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Sherwood et al.

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(45) **Date of Patent: Apr. 3, 2001**

(54) **ENROLLMENT IN SPEECH RECOGNITION**

(75) Inventors: **Stefan Sherwood**, Belmont; **Toffee A. Albina**; **David E. Wald**, both of Cambridge; **Noah M. Graham**, Newton; **Joel Gould**, Winchester; **Francesco Scattone**, Medfield, all of MA (US)

(73) Assignee: **Dragon Systems, Inc.**, Newton, MA (US)

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(22) Filed: **Mar. 28, 1997**

(51) **Int. Cl.**[7] **G10L 5/00**; G10L 5/06

(52) **U.S. Cl.** **704/244**; 704/235

(58) **Field of Search** 704/200, 201, 704/231, 243–245, 235, 260

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Primary Examiner—David D. Knepper

(57) **ABSTRACT**

Enrolling a user in a speech recognition system includes analyzing acoustic content of a user utterance and determining whether the utterance matches a portion of an enrollment text. If the user utterance matches a portion of the enrollment text, the acoustic content is used to update acoustic models corresponding to the portion of the enrollment text.

20 Claims, 16 Drawing Sheets

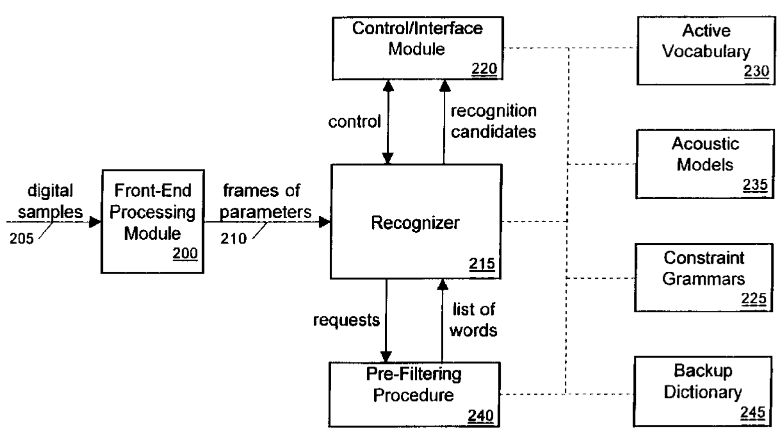

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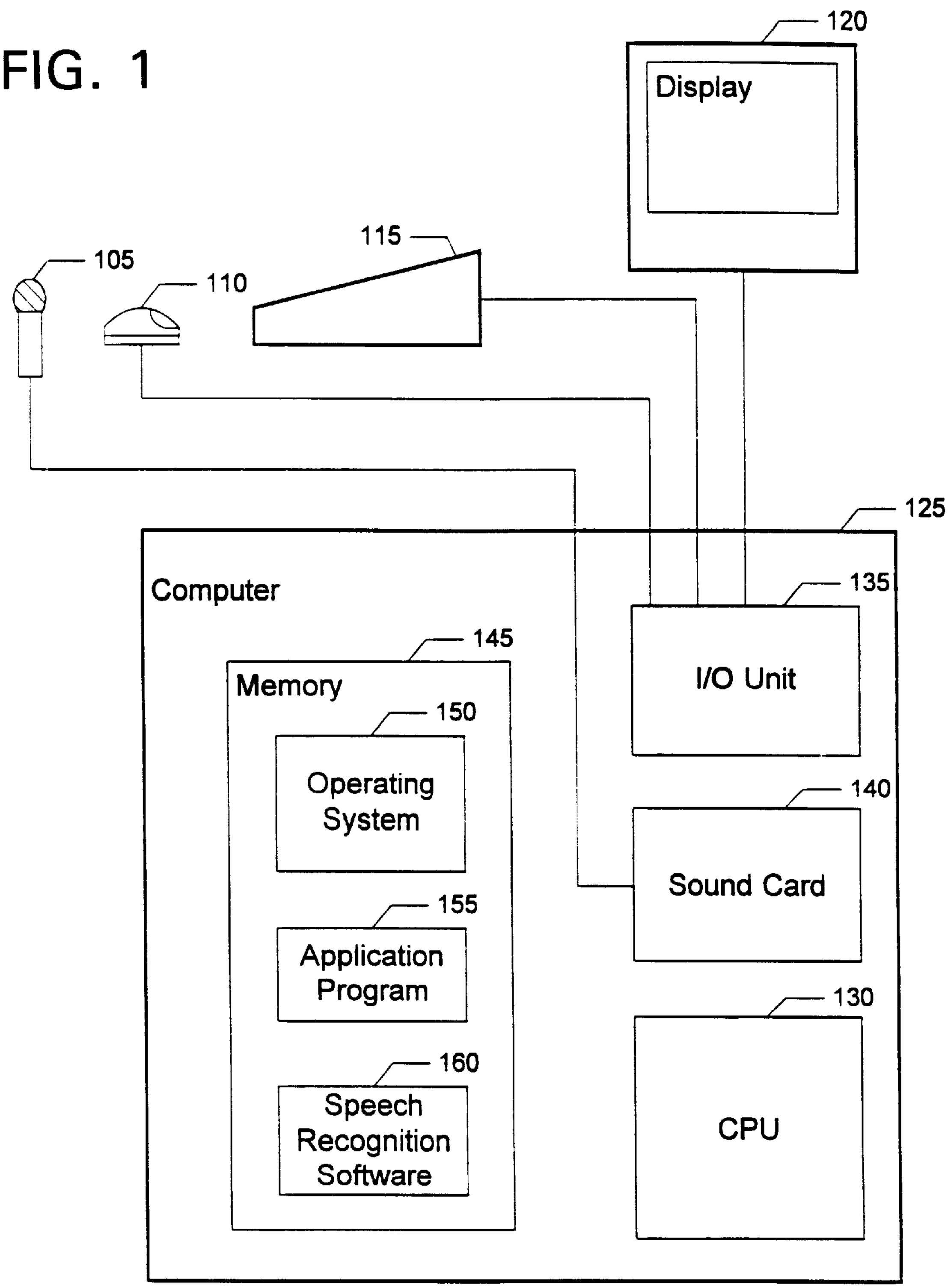
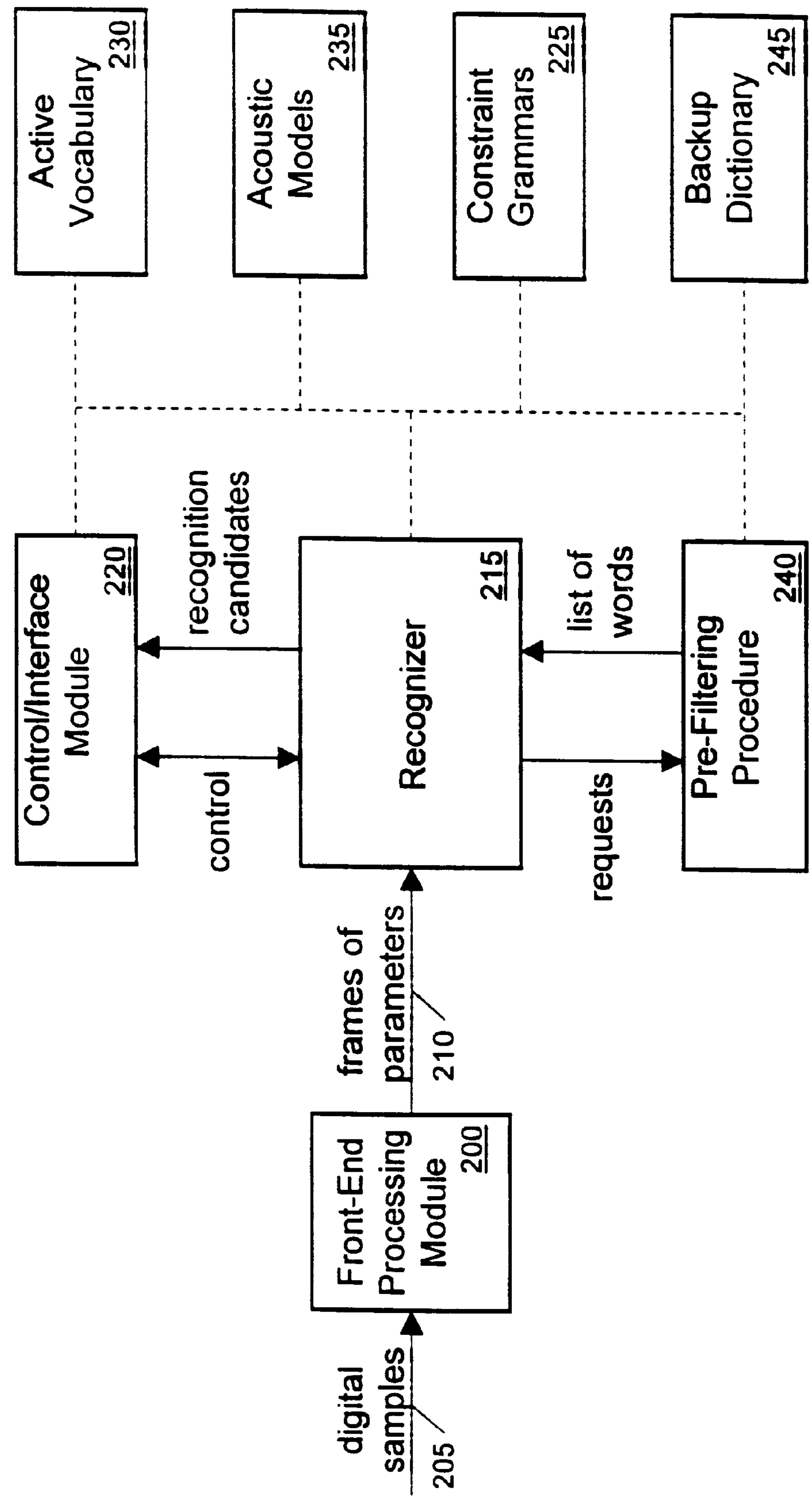
FIG. 1

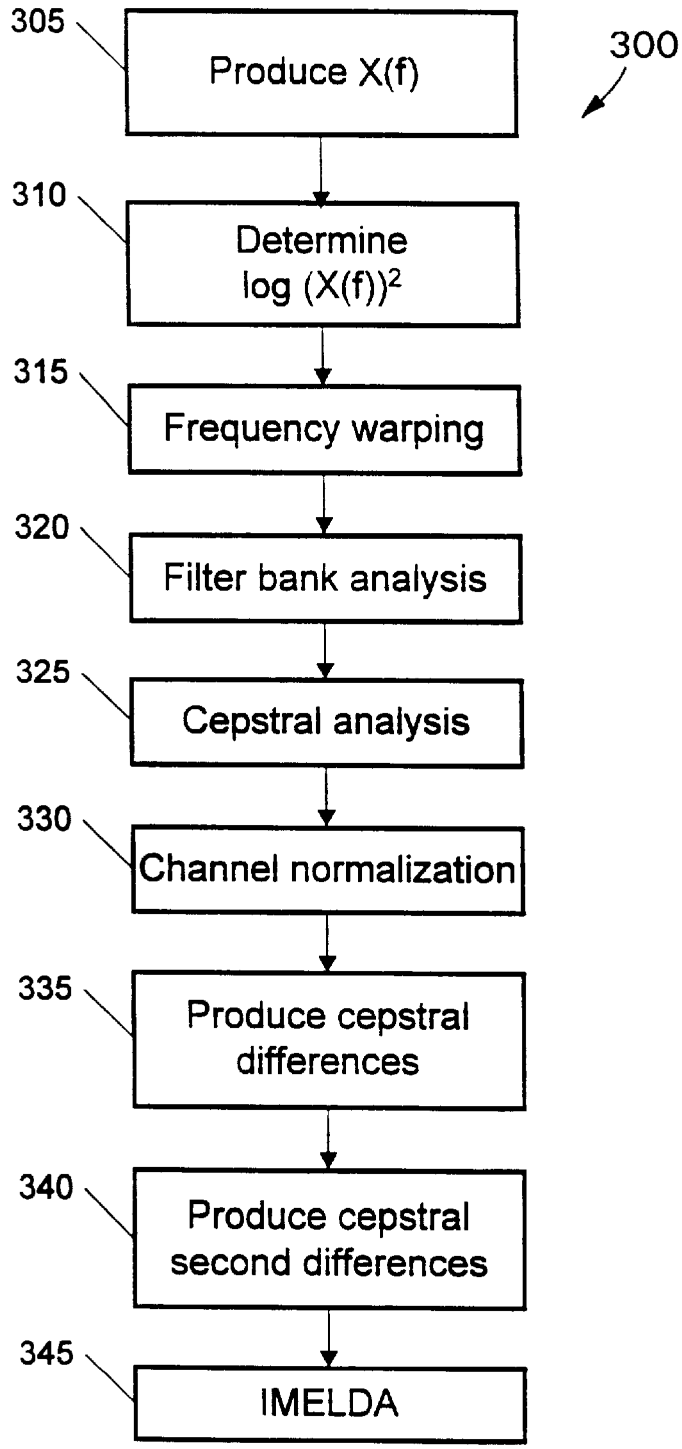


120
Display
115
105
110
125
Computer
135
I/O Unit
145
Memory
150
Operating System
140
Sound Card
155
Application Program
130
CPU
160
Speech Recognition Software



Active Vocabulary 230
Acoustic Models 235
Constraint Grammars 225
Backup Dictionary 245
Control/Interface Module 220
recognition candidates
control
Recognizer 215
list of words
requests
Pre-Filtering Procedure 240
frames of parameters
210
Front-End Processing Module 200
digital samples
205

FIG. 2



300
305
Produce X(f)
310
Determine
log (X(f))²
315
Frequency warping
320
Filter bank analysis
325
Cepstral analysis
330
Channel normalization
335
Produce cepstral
differences
340
Produce cepstral
second differences
345
IMELDA

FIG. 3

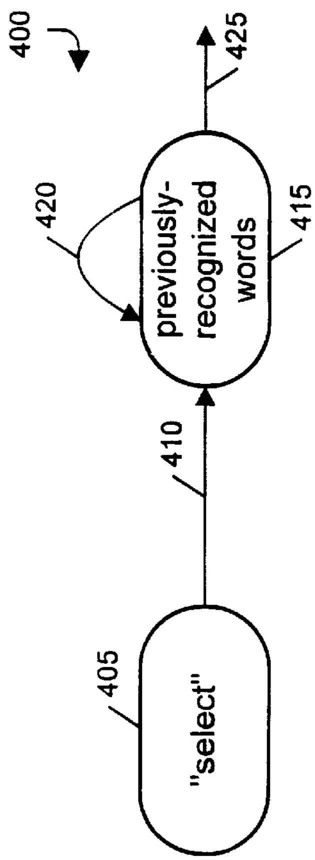

400
"select"
405
410
previously-recognized words
420
415
425

FIG. 4A

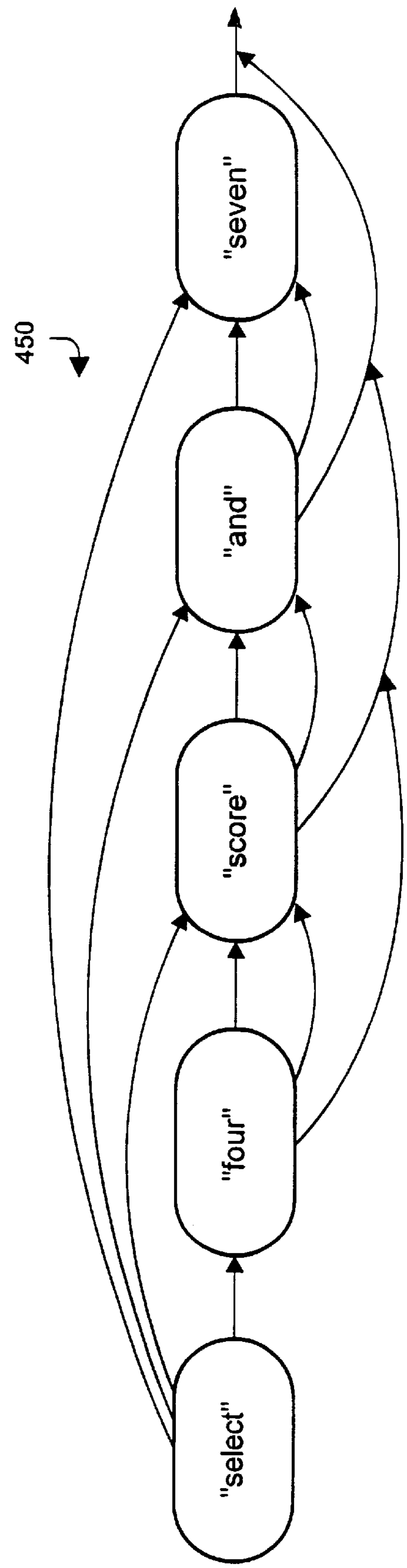
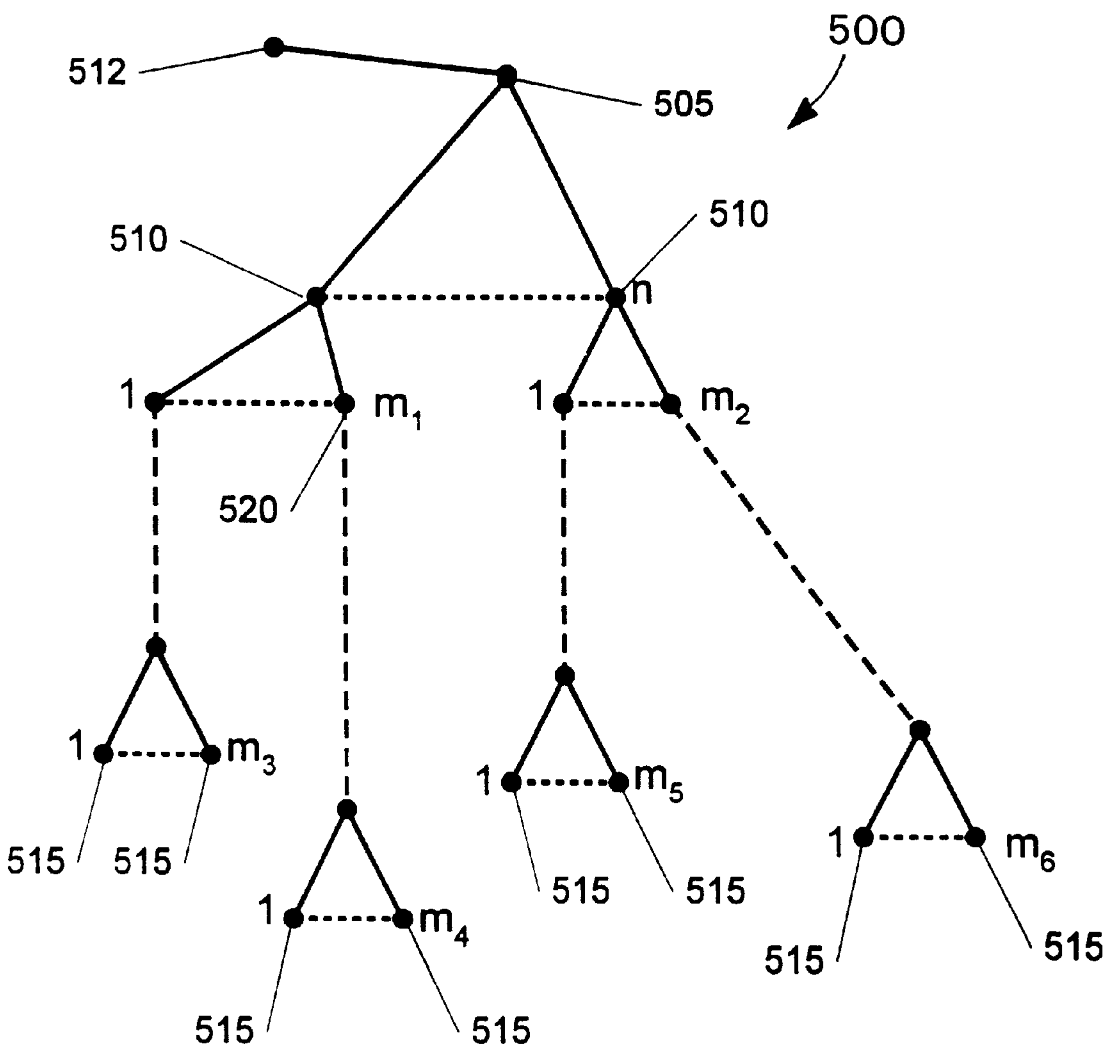

450
"select"
"four"
"score"
"and"
"seven"

FIG. 4B



500
512
505
510
510
n
1
m_1
1
m_2
520
1
m_3
515
515
1
m_4
515
515
1
m_5
515
515
1
m_6
515
515

FIG. 5

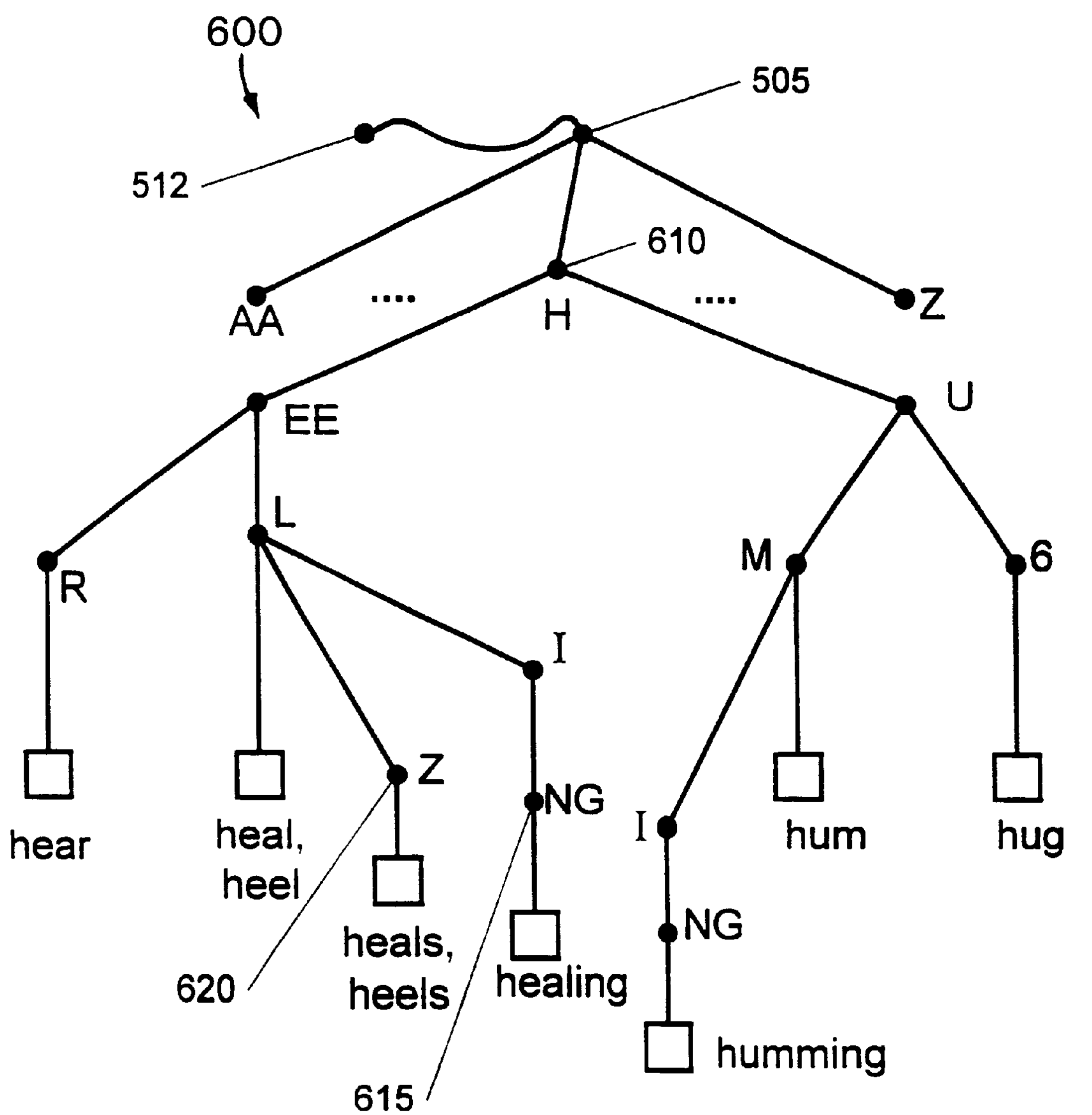

600
505
512
610
AA
....
H
....
Z
EE
U
L
R
M
6
I
Z
NG
I
hear
heal,
heel
hum
hug
NG
heals,
heels
healing
620
humming
615

FIG. 6

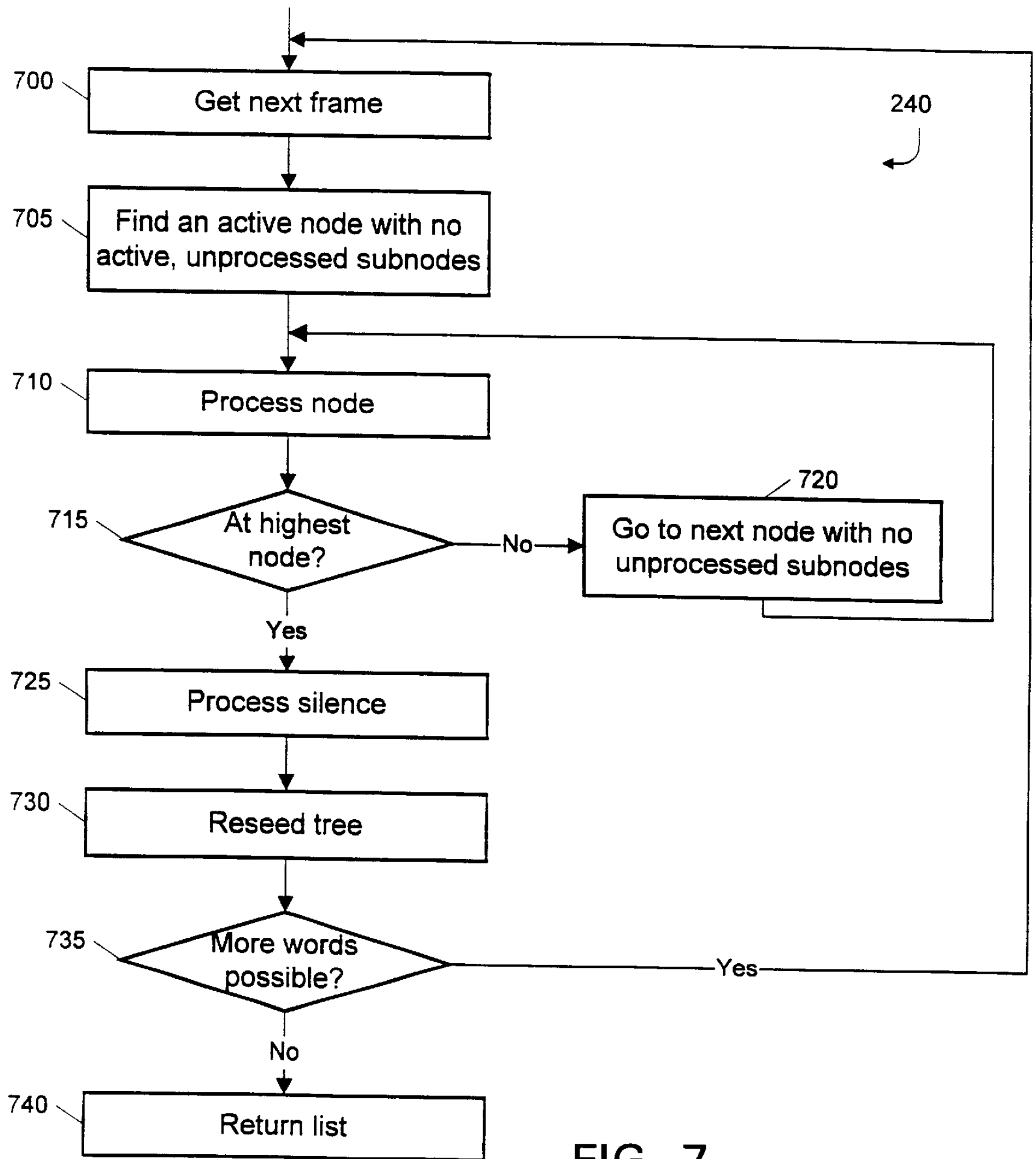

700
Get next frame
240
705
Find an active node with no active, unprocessed subnodes
710
Process node
720
715
At highest node?
No
Go to next node with no unprocessed subnodes
Yes
725
Process silence
730
Reseed tree
735
More words possible?
Yes
No
740
Return list

FIG. 7

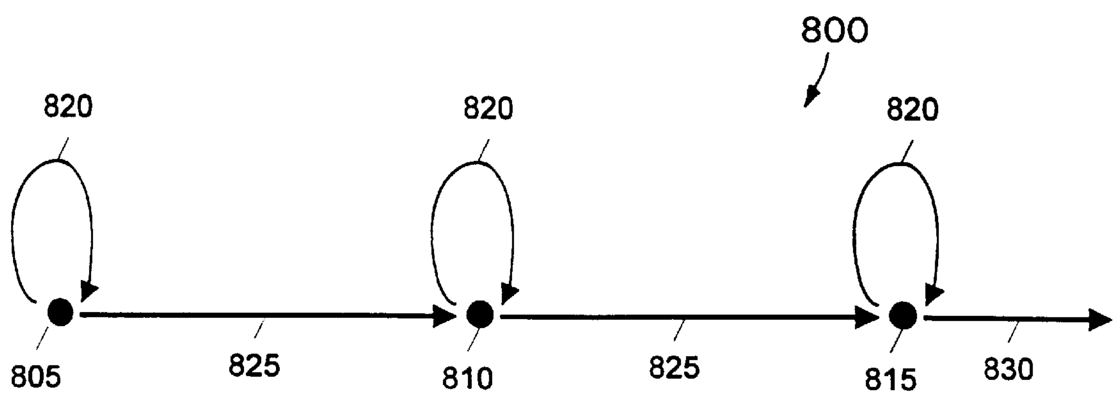


FIG. 8A

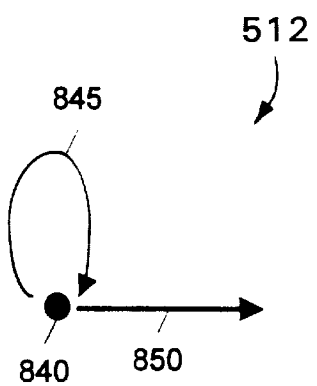


FIG. 8B

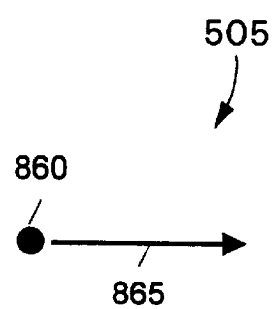


FIG. 8C

	Frame	840 ("A")	805 ("B")	810 ("C")	815 ("D")	Next Node ("N")
900	0	0	-----	-----	-----	-----
905	1	$S_{A1}=A_{A1}$	$S_{B1}=A_{B1}$	-----	-----	-----
910	2	$S_{A2}=S_{A1}+A_{A2}$	$S_{B2}=\min(S_{B1}+stay_B, S_{A1})+A_{B2}$	$S_{C2}=S_{B1}+leave_B+A_{C2}$	-----	-----
915	3	$S_{A3}=S_{A2}+A_{A3}$	$S_{B3}=\min(S_{B2}+stay_B, S_{A2})+A_{B3}$	$S_{C3}=\min(S_{C2}+stay_C, S_{B2}+leave_B)+A_{C3}$	$S_{D3}=S_{C2}+leave_C+A_{D3}$	-----
920	4	$S_{A4}=S_{A3}+A_{A4}$	$S_{B4}=\min(S_{B3}+stay_B, S_{A3})+A_{B4}$	$S_{C4}=\min(S_{C3}+stay_C, S_{B3}+leave_B)+A_{C4}$	$S_{D4}=\min(S_{D3}+stay_D, S_{c3}+leave_C)+A_{D4}$	$S_{N4}=S_{D2}+leave_D+A_{D4}$
925	n	$S_{An}=S_{An-1}+A_{An}$	$S_{Bn}=\min(S_{Bn-1}+stay_B, S_{An-1})+A_{Bn}$	$S_{Cn}=\min(S_{Cn-1}+stay_C, S_{Bn-1}+leave_B)+A_{Cn}$	$S_{Dn}=\min(S_{Dn-1}+stay_D, S_{cn-1}+leave_C)+A_{Dn}$	$S_{NN}=\min(S_{Nn-1}+stay_M, S_{Mn-1}+leave_M)+A_{Nm}$

FIG. 9

	Frame	810 ("A")	805 ("B")	810 ("C")	815 ("D")	Next Node ("N")
900	0	$S_{AO}=0$	-----	-----	-----	-----
905	1	$S_{A1}=f(S_{AO}, A_{A1})$	$S_{B1}=f(S_{AO}, A_{B1})$	-----	-----	-----
910	2	$S_{A2}=f(S_{A1}, A_{A2})$	$S_{B2}=f(S_{B1}, stay_B, S_{A1}, A_{B2})$	$S_{C2}=f(S_{B1}, leave_B, A_{C2})$	-----	-----
915	3	$S_{A3}=f(S_{A2}, A_{A3})$	$S_{B3}=f(S_{B2}, stay_B, S_{A2}, A_{B3})$	$S_{C3}=f(S_{C2}, stay_C, S_{B2}, leave_B, A_{C3})$	$S_{D3}=f(S_{C2}, leave_C, A_{D3})$	-----
920	4	$S_{A4}=f(S_{A3}, A_{A4})$	$S_{B4}=f(S_{B3}, stay_B, S_{A3}, A_{B4})$	$S_{C4}=f(S_{C3}, stay_C, S_{B3}, leave_B, A_{C4})$	$S_{D4}=f(S_{D3}, stay_D, S_{c3}, leave_C, A_{D4})$	$S_{N4}=f(S_{D3}, leave_D, A_{D3})$
925	n	$S_{An}=f(S_{An-1}, A_{An})$	$S_{Bn}=f(S_{Bn-1}, stay_B, S_{An-1}, A_{Bn})$	$S_{Cn}=f(S_{Cn-1}, stay_C, S_{Bn-1}, leave_B, A_{Cn})$	$S_{Dn}=f(S_{Dn-1}, stay_D, S_{cn-1}, leave_C, A_{Dn})$	$S_{Nn}=f(S_{Dn-1}, leave_N, A_{Nn})$

FIG. 10

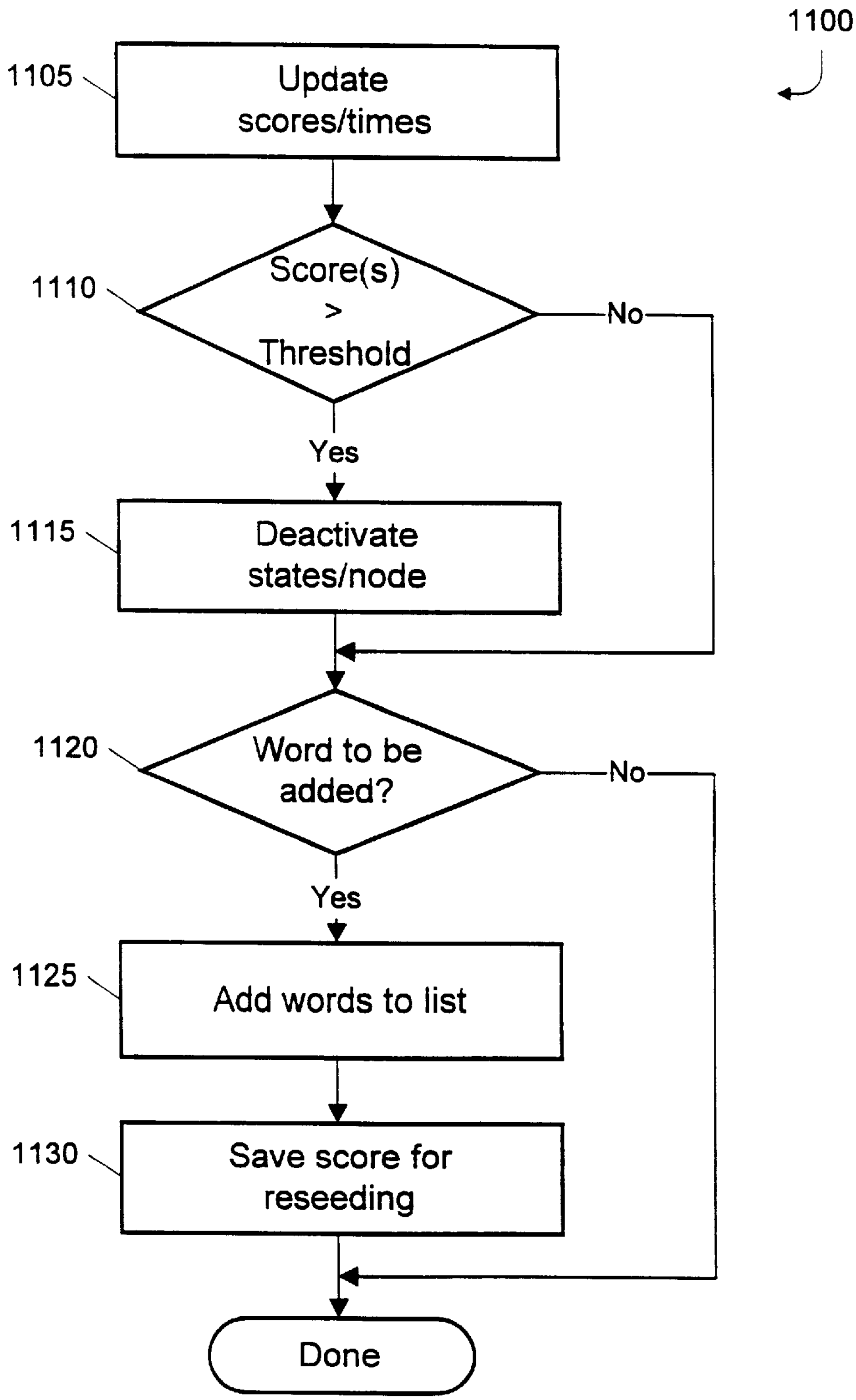
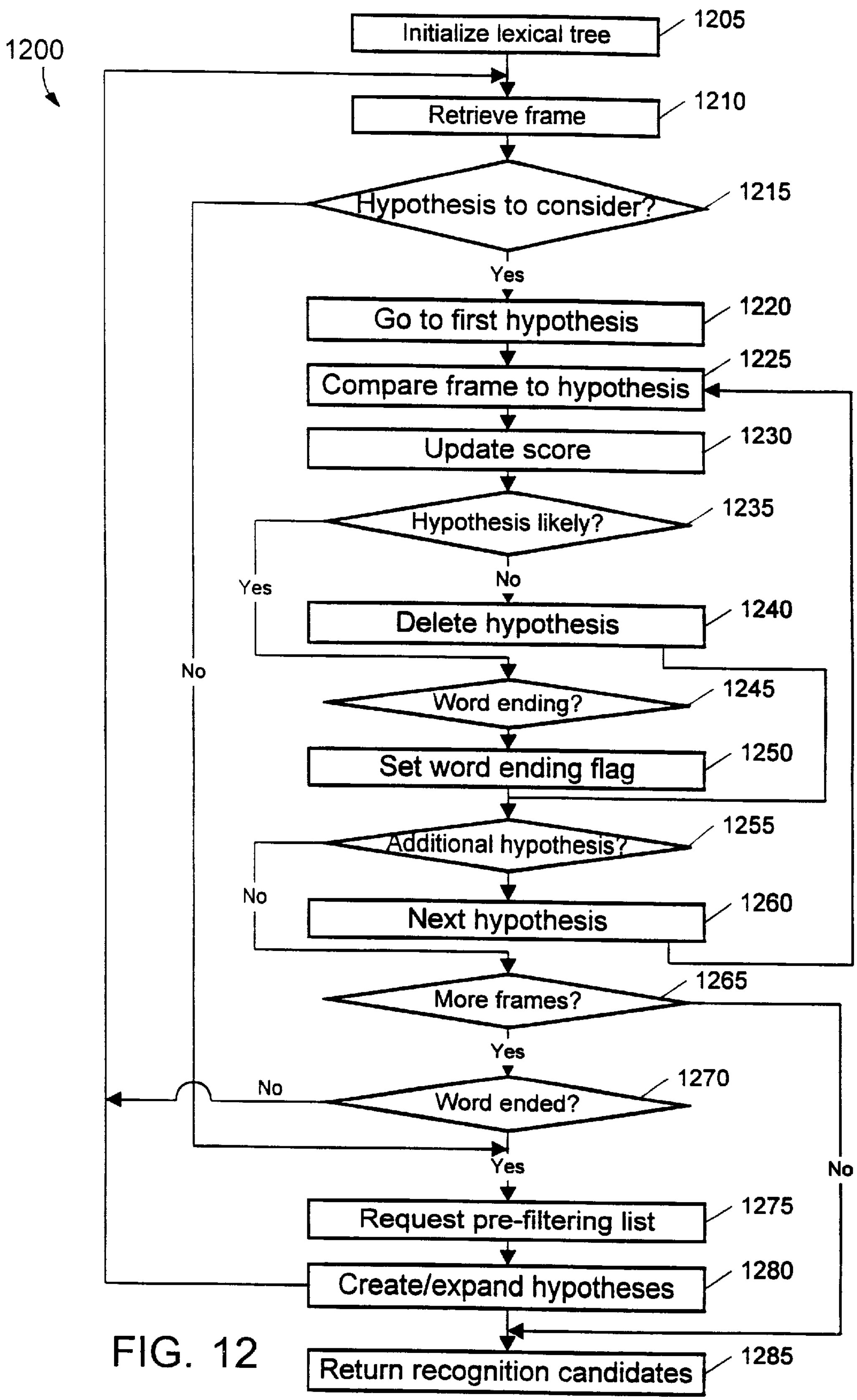

1100
1105
Update scores/times
1110
Score(s) > Threshold
No
Yes
1115
Deactivate states/node
1120
Word to be added?
No
Yes
1125
Add words to list
1130
Save score for reseeding
Done

FIG. 11



1200
Initialize lexical tree
1205
Retrieve frame
1210
Hypothesis to consider?
1215
Yes
No
Go to first hypothesis
1220
Compare frame to hypothesis
1225
Update score
1230
Hypothesis likely?
1235
Yes
No
Delete hypothesis
1240
Word ending?
1245
Set word ending flag
1250
Additional hypothesis?
1255
No
Next hypothesis
1260
More frames?
1265
Yes
No
Word ended?
1270
No
Yes
Request pre-filtering list
1275
Create/expand hypotheses
1280
Return recognition candidates
1285

FIG. 12

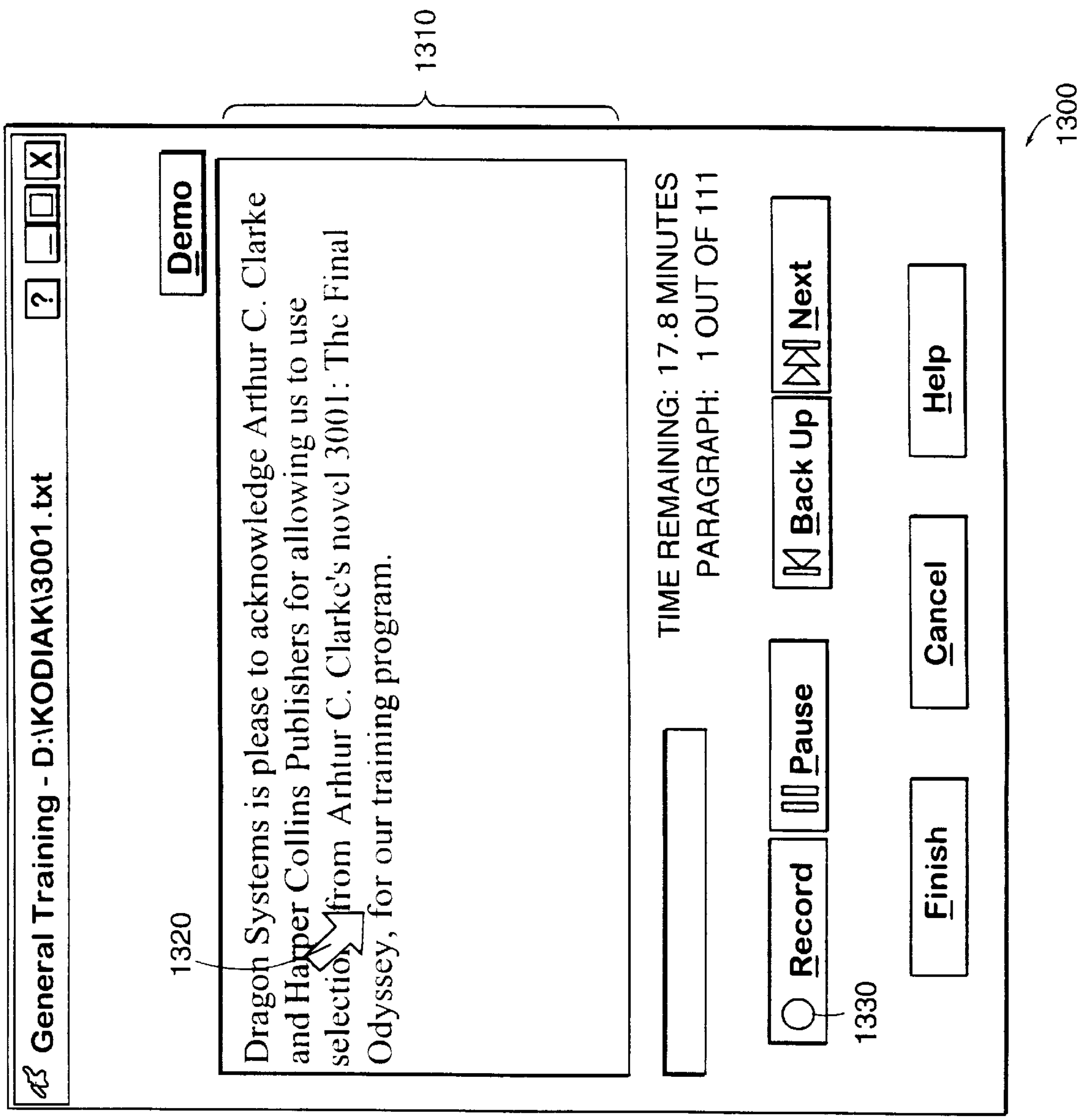

1310
1300
General Training - D:\KODIAK\3001.txt
?
X
Demo
1320
Dragon Systems is please to acknowledge Arthur C. Clarke and Harper Collins Publishers for allowing us to use selection from Arhtur C. Clarke's novel 3001: The Final Odyssey, for our training program.
TIME REMAINING: 17.8 MINUTES
PARAGRAPH: 1 OUT OF 111
Record
Pause
Back Up
Next
1330
Finish
Cancel
Help

FIG. 13

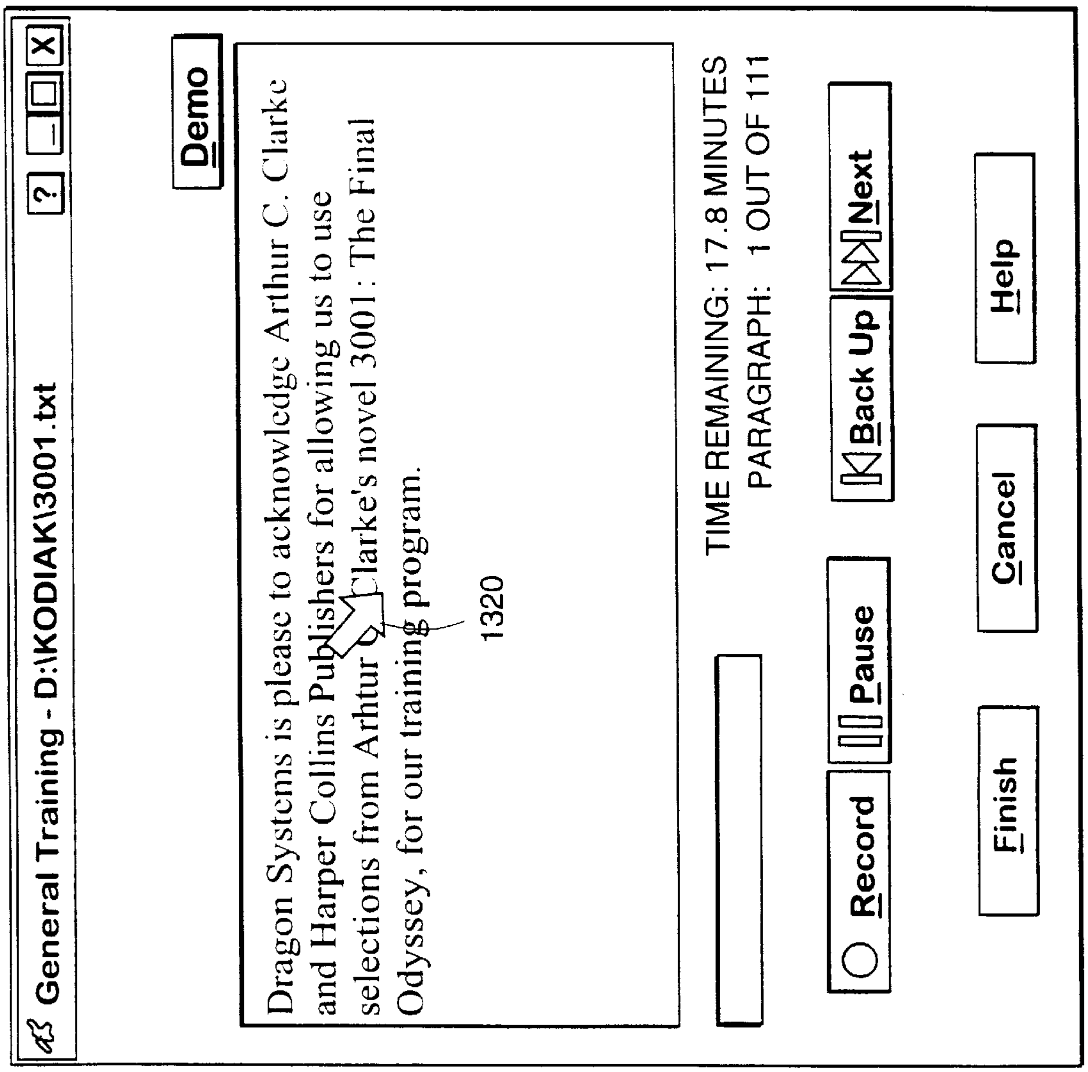

General Training - D:\KODIAK\3001.txt
?
Demo
Dragon Systems is please to acknowledge Arthur C. Clarke and Harper Collins Publishers for allowing us to use selections from Arhtur C. Clarke's novel 3001: The Final Odyssey, for our training program.
1320
TIME REMAINING: 17.8 MINUTES
PARAGRAPH: 1 OUT OF 111
Record
Pause
Back Up
Next
Finish
Cancel
Help

FIG. 14

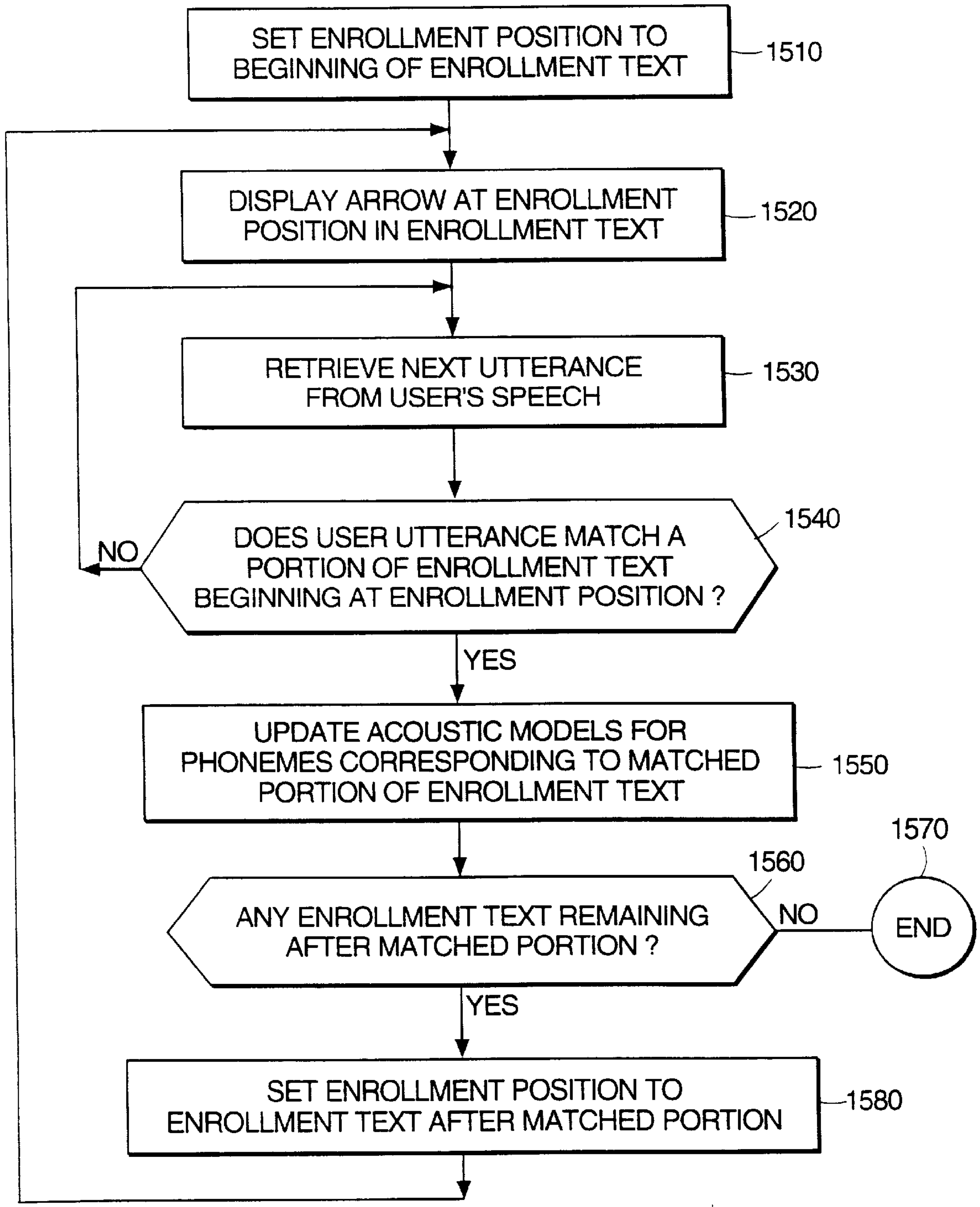

SET ENROLLMENT POSITION TO BEGINNING OF ENROLLMENT TEXT
1510
DISPLAY ARROW AT ENROLLMENT POSITION IN ENROLLMENT TEXT
1520
RETRIEVE NEXT UTTERANCE FROM USER'S SPEECH
1530
DOES USER UTTERANCE MATCH A PORTION OF ENROLLMENT TEXT BEGINNING AT ENROLLMENT POSITION ?
1540
NO
YES
UPDATE ACOUSTIC MODELS FOR PHONEMES CORRESPONDING TO MATCHED PORTION OF ENROLLMENT TEXT
1550
ANY ENROLLMENT TEXT REMAINING AFTER MATCHED PORTION ?
1560
NO
END
1570
YES
SET ENROLLMENT POSITION TO ENROLLMENT TEXT AFTER MATCHED PORTION
1580

FIG. 15

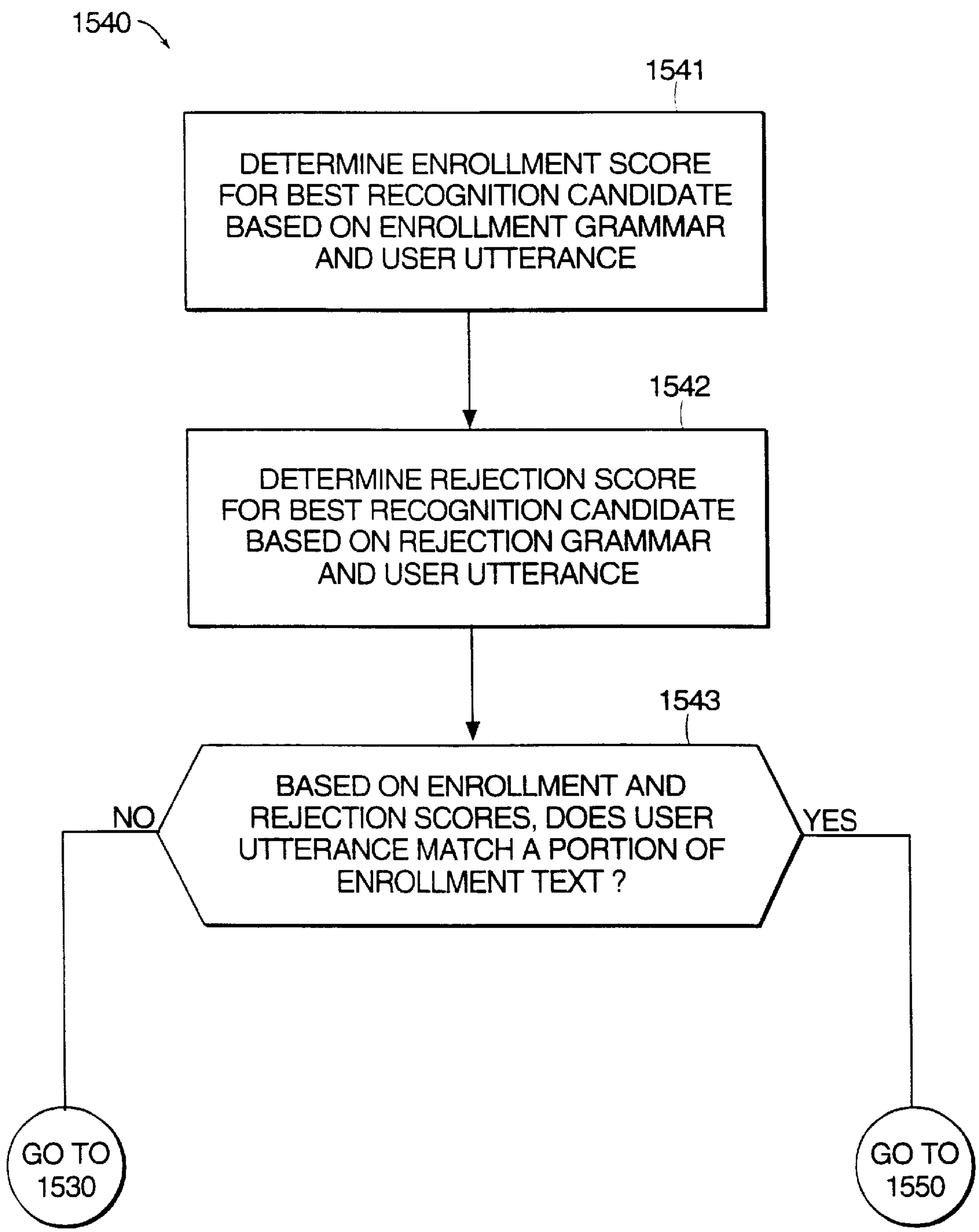

1540
1541
DETERMINE ENROLLMENT SCORE FOR BEST RECOGNITION CANDIDATE BASED ON ENROLLMENT GRAMMAR AND USER UTTERANCE
1542
DETERMINE REJECTION SCORE FOR BEST RECOGNITION CANDIDATE BASED ON REJECTION GRAMMAR AND USER UTTERANCE
1543
BASED ON ENROLLMENT AND REJECTION SCORES, DOES USER UTTERANCE MATCH A PORTION OF ENROLLMENT TEXT ?
NO
YES
GO TO 1530
GO TO 1550

FIG. 16

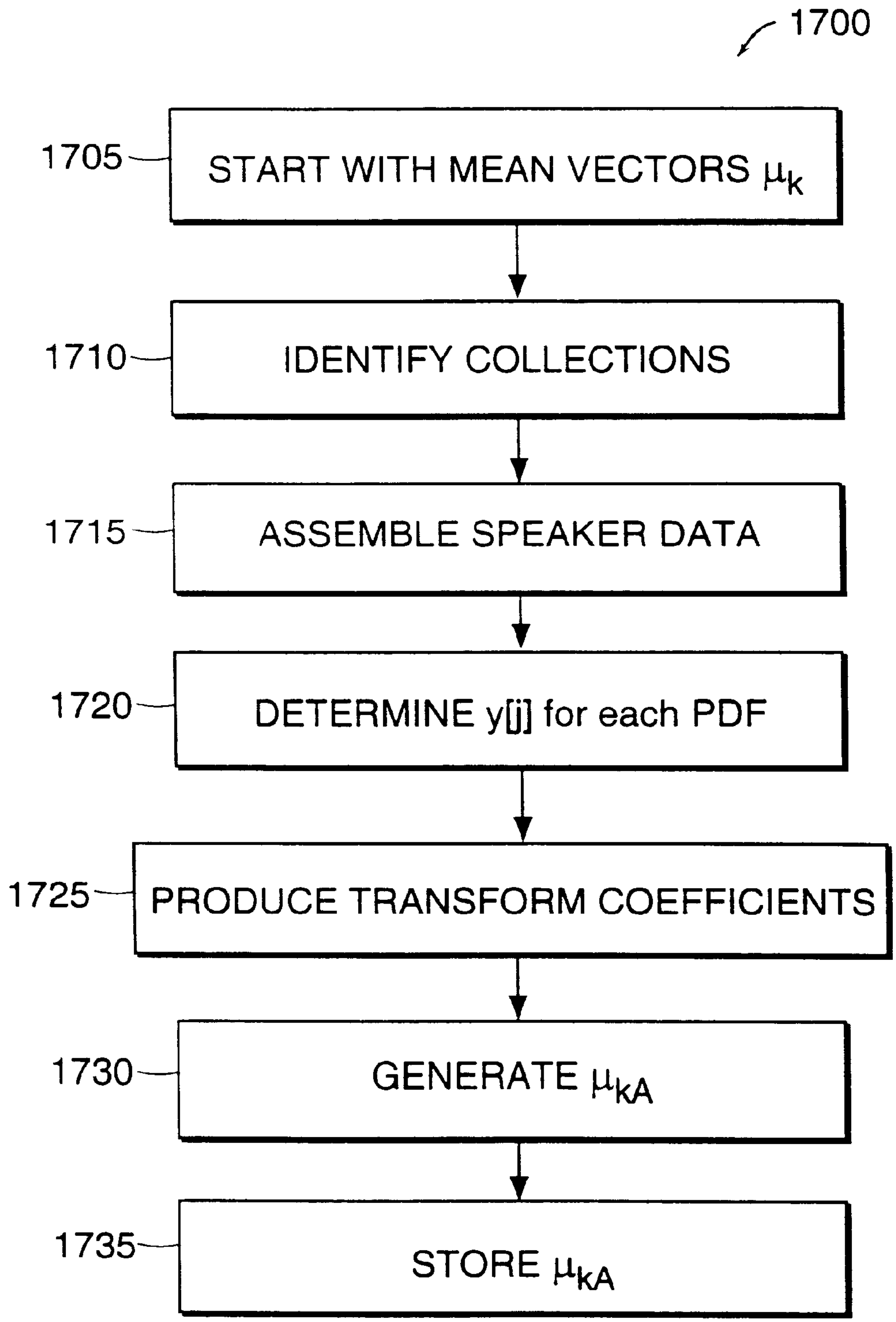

1700
1705
START WITH MEAN VECTORS μ_k
1710
IDENTIFY COLLECTIONS
1715
ASSEMBLE SPEAKER DATA
1720
DETERMINE y[j] for each PDF
1725
PRODUCE TRANSFORM COEFFICIENTS
1730
GENERATE μ_{kA}
1735
STORE μ_{kA}

FIG. 17

ENROLLMENT IN SPEECH RECOGNITION

BACKGROUND

The invention relates to enrollment in speech recognition.

A speech recognition system analyzes a user's speech to determine what the user said. Most speech recognition systems are frame-based. In a frame-based system, a processor divides a signal descriptive of the speech to be recognized into a series of digital frames, each of which corresponds to a small time increment of the speech.

A speech recognition system may be a "discrete" system that recognizes discrete words or phrases but which requires the user to pause briefly between each discrete word or phrase. Alternatively, a speech recognition system may be a "continuous" system that can recognize spoken words or phrases regardless of whether the user pauses between them. Continuous speech recognition systems typically have a higher incidence of recognition errors in comparison to discrete recognition systems due to complexities of recognizing continuous speech. A more detailed description of continuous speech recognition is provided in U.S. Pat. No. 5,202,952, entitled "LARGE-VOCABULARY CONTINUOUS SPEECH PREFILTERING AND PROCESSING SYSTEM," which is incorporated by reference.

In general, the processor of a continuous speech recognition system analyzes "utterances" of speech. An utterance includes a variable number of frames and corresponds, for example, to a period of speech followed by a pause of at least a predetermined duration.

The processor determines what the user said by finding acoustic models that best match the digital frames of an utterance, and identifying text that corresponds to those acoustic models. An acoustic model may correspond to a word, phrase or command from a vocabulary. An acoustic model also may represent a sound, or phoneme, that corresponds to a portion of a word. Collectively, the constituent phonemes for a word represent the phonetic spelling of the word. Acoustic models also may represent silence and various types of environmental noise.

The words or phrases corresponding to the best matching acoustic models are referred to as recognition candidates. The processor may produce a single recognition candidate for an utterance, or may produce a list of recognition candidates. Speech recognition techniques are discussed in U.S. Pat. No. 4,805,218, entitled "METHOD FOR SPEECH ANALYSIS AND SPEECH RECOGNITION", which is incorporated by reference.

An acoustic model generally includes data describing how a corresponding speech unit (e.g., a phoneme) is spoken by a variety of speakers. To increase the accuracy with which an acoustic model represents a particular user's speech, and thereby to decrease the incidence of recognition errors, the speech recognition system may modify the acoustic models to correspond to the particular user's speech. This modification may be based on samples of the user's speech obtained during an initial enrollment session and during use of the system.

Enrollment sessions for previous speech recognition systems typically required a user to read from a list of words or to read specific words in response to prompts. For example, DragonDictate® for Windows®, available from Dragon Systems, Inc. of Newton, Mass., included a quick enrollment session that prompted a new user to speak each word of a small set of words, and then adapted the acoustic models based on the user's speech.

SUMMARY

In general, in one aspect, the invention features enrolling a user in a speech recognition system by analyzing acoustic content of a user utterance and determining, based on the analysis, whether the user utterance matches a portion of an enrollment text. The acoustic content of the user utterance is used to update acoustic models corresponding to the portion of the enrollment text if the user utterance matches a portion of the enrollment text.

Certain implementations of the invention may include one or more of the following features. An enrollment grammar corresponding to the enrollment text may be used to determine whether the user utterance matches a portion of the enrollment text. A rejection grammar may be used to determine whether the user utterance matches a portion of the enrollment text. The rejection grammar may be a phoneme grammar and may model an utterance using a set of phonemes that is smaller than a set of phonemes used by the enrollment grammar.

An enrollment position may be determined within the enrollment text, and a user utterance may be required to match a portion of the enrollment text that begins at the enrollment position. The enrollment text and the enrollment position may be displayed. If the user utterance matches a portion of the enrollment text, the enrollment position is advanced past the matching portion in the enrollment text.

The enrollment text may be selected from a plurality of enrollment texts. Each of the enrollment texts has a corresponding enrollment grammar. The enrollment grammar corresponding to the selected enrollment text is used to determine whether the user utterance matches a portion of the enrollment text.

An enrollment text may be received from a user. An enrollment grammar corresponding to the received enrollment text may be generated for use in determining whether the user utterance matches a portion of the enrollment text.

The user utterance may be ignored if it does not match a portion of the enrollment text.

In general, in another aspect, the invention features enrolling a user into a speech recognition system by displaying an enrollment text and an enrollment position within the enrollment text. When a user utterance is received, a determination is made as to whether a match exists between the user utterance and a portion of the enrollment text beginning at the enrollment position. The enrollment position is updated if a match exists, and the updated enrollment position is displayed.

Certain implementations of the invention may include one or more of the following features. The enrollment position may be displayed using a marker at the enrollment position. The enrollment position may be displayed by highlighting the enrollment text at the enrollment position, and may be displayed using a cursor at the enrollment position.

In general, in another aspect, the invention features computer software, residing on a computer-readable storage medium, comprising instructions for causing a computer to implement the techniques described above.

In general, in another aspect, the invention features a speech recognition system for enrolling a user. The system includes a display for displaying an enrollment text to a user, an input device for receiving speech signals, and a processor. The processor determines a user utterance from a received speech signal, analyzes acoustic content of the user utterance, and determines, based on the acoustic analysis, whether the user utterance matches a portion of an enroll-

ment text. The processor then uses the user utterance to update acoustic models corresponding to the portion of the enrollment text if the user utterance matches a portion of the enrollment text.

Among the advantages of the invention is that by determining and ignoring user utterances that do not match a portion of the enrollment text, the acoustic models of the enrollment program are not incorrectly updated based on the user utterance.

Other features and advantages of the invention will become apparent from the following description and from the claims.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a block diagram of a speech recognition system.

FIG. **2** is a block diagram of speech recognition software of the system of FIG. **1**.

FIG. **3** is a flow chart of a signal processing procedure performed by the software of FIG. **2**.

FIGS. **4**A and **4**B are state diagrams of a constraint grammar.

FIG. **5** is a graph of a lexical tree.

FIG. **6** is a graph of a portion of the lexical tree of FIG. **5**.

FIG. **7** is a flow chart of a pre-filtering procedure performed by the software of FIG. **2**.

FIGS. **8**A, **8**B and **8**C are state graphs representing nodes of the lexical tree of FIG. **5**.

FIGS. **9** and **10** are charts of scores corresponding to the states of the state graphs of FIGS. **8**A, **8**B and **8**C.

FIG. **11** is a flow chart of a procedure for processing nodes of a lexical tree.

FIG. **12** is a flow chart of a speech recognition procedure.

FIGS. **13** and **14** show a user interface for an enrollment program.

FIGS. **15** and **16** are flow charts of enrollment procedures.

FIG. **17** is a flow chart of a model-adaptation procedure.

DESCRIPTION

FIG. **1** is a block diagram of a speech recognition system **100**. The system includes input/output (I/O) devices (e.g., microphone **105**, mouse **110**, keyboard **115**, and display **120**) and a general purpose computer **125** having a processor **130**, an I/O unit **135** and a sound card **140**. A memory **145** stores data and programs such as an operating system **150**, an application program **155** (e.g., a word processing program), and speech recognition software **160**.

The microphone **105** receives the user's speech and conveys the speech, in the form of an analog signal, to the sound card **140**, which in turn passes the signal through an analog-to-digital (A/D) converter to transform the analog signal into a set of digital samples. Under control of the operating system **150** and the speech recognition software **160**, the processor **130** identifies utterances in the user's continuous speech. Utterances are separated from one another by a pause having a sufficiently-large, predetermined duration (e.g., 160–250 milliseconds). Each utterance may include one or more words of the user's speech.

FIG. **2** illustrates components of the speech recognition software **160**. For ease of discussion, the following description indicates that the components carry out operations to achieve specified results. However, it should be understood that each component actually causes the processor **130** to operate in the specified manner.

Initially, a front end processing module **200** converts the digital samples **205** from the sound card **140** into frames of parameters **210** that represent the frequency content of an utterance. Each frame includes 24 parameters and represents a short portion (e.g., 10 milliseconds) of the utterance.

As shown in FIG. **3**, the front end processing module **200** produces a frame from digital samples according to a procedure **300**. The module first produces a frequency domain representation X(f) of the portion of the utterance by performing a Fast Fourier Transform (FFT) on the digital samples (step **305**). Next, the module determines $\log(X(f))^2$ (step **310**). The module may then perform frequency warping (step **315**) and a filter bank analysis (step **320**) to achieve speaker normalization. See S. Wegmann et al., "Speaker Normalization on Conversational Speech," *Proc.* 1996 *ICASSP*, pp. I1.339–I.341, which is incorporated by reference. In general, speaker normalization is used only after acoustic models have been adapted to a particular speaker using an enrollment program as described below.

From the normalized results, the module performs cepstral analysis to produce 12 cepstral parameters (step **325**). The module generates the cepstral parameters by performing an inverse cosine transformation on the logarithms of the frequency parameters. Cepstral parameters and cepstral differences have been found to emphasize information important to speech recognition more effectively than do the frequency parameters. After performing channel normalization of the cepstral parameters (step **330**), the module produces 12 cepstral differences (i.e., the differences between cepstral parameters in successive frames) (step **335**) and 12 cepstral second differences (i.e., the differences between cepstral differences in successive frames) (step **340**). Finally, the module performs an IMELDA linear combination transformation to select the 24 most useful parameters from the 12 cepstral parameters, the 12 cepstral differences, and the 12 cepstral second differences (step **345**).

Referring again to FIG. **2**, a recognizer **215** receives and processes the frames of an utterance to identify text corresponding to the utterance. The recognizer entertains several hypotheses about the text and associates a score with each hypothesis. The score reflects the probability that a hypothesis corresponds to the user's speech. For ease of processing, scores are maintained as negative logarithmic values. Accordingly, a lower score indicates a better match (a high probability) while a higher score indicates a less likely match (a lower probability), with the likelihood of the match decreasing as the score increases. After processing the utterance, the recognizer provides the best-scoring hypotheses to the control/interface module **220** as a list of recognition candidates, where each recognition candidate corresponds to a hypothesis and has an associated score. Some recognition candidates may correspond to text while other recognition candidates correspond to commands. Commands may include words, phrases or sentences recognized by a constraint grammar **225**, explained in greater detail below.

The recognizer **215** processes the frames **210** of an utterance in view of one or more constraint grammars **225**. A constraint grammar, also referred to as a template or restriction rule, may be, for example, a limitation on the words that may correspond to an utterance, a limitation on the order or grammatical form of the words, or both. For example, a constraint grammar for menu-manipulation commands may include only entries from the menu (e.g., "file", "edit") or command words for navigating through the menu (e.g., "up", "down", "top", "bottom"). Different constraint

grammars may be active at different times. For example, a constraint grammar may be associated with a particular application program **155** and may be activated when the user opens the application program and deactivated when the user closes the application program. The recognizer **215** discards any hypothesis that does not comply with an active constraint grammar. In addition, the recognizer **215** may adjust the score of a hypothesis associated with a particular constraint grammar based on characteristics of the constraint grammar.

One constraint grammar **225** that may be used by the speech recognition software **160** is a large vocabulary dictation grammar. The large vocabulary dictation grammar identifies words included in the active vocabulary **230**, which is the vocabulary of words known to the software. The large vocabulary dictation grammar also indicates the frequency with which words occur. A language model associated with the large vocabulary dictation grammar may be a unigram model that indicates the frequency with which a word occurs independently of context, or a bigram model that indicates the frequency with which word occurs in the context of a preceding word. For example, a bigram model may indicate that a noun or adjective is more likely to follow the word "the" than is a verb or preposition.

The active vocabulary **230** uses a pronunciation model in which each word is represented by a series of phonemes that comprise the phonetic spelling of the word. Each phoneme may be represented as a triphone, a context-dependent phoneme, that includes three nodes. For example, the triphone "abc" represents the phoneme "b" in the context of the phonemes "a" and "c", with the phoneme "b" being preceded by the phoneme "a" and followed by the phoneme "c".

The phonemes are represented by acoustic models **235**. In the case of triphones, the acoustic models **235** represent each triphone node as a mixture of Gaussian probability density functions ("PDFs"). For example, node "i" of a triphone "abc" may be represented as ab^ic:

$$ab^ic = \sum_k w_k N(\mu_k, c_k),$$

where each w_k is a mixture weight,

$$\sum_k w_k = 1,$$

μ_k is a mean vector for the probability density function ("PDF") N_k, and c_k is the covariance matrix for the PDF N_k. Like the frames in the sequence of frames, the vectors μ_k each include 24 parameters. The matrices c_k are 24×24 matrices. Each triphone node may be represented as a mixture of up to 16 different PDFs.

A particular PDF may be used in the representation of multiple triphone nodes. Accordingly, the acoustic models **235** represent each triphone node as a collection of mixture weights w_k associated with up to 16 different PDFs N_k and separately represent each PDF N_K using a mean vector μ_k and a covariance matrix c_k.

A large vocabulary dictation grammar may include multiple dictation topics (e.g., "medical" or "legal"), each having its own vocabulary file, allowing each dictation topic to have its own language model. A dictation topic will consists of a set of words which represents the active vocabulary **230**. In a typical example, a topic may include approximately 30,000 words that are considered for normal recognition.

A complete dictation vocabulary consists of the active vocabulary **230** plus a backup vocabulary **245**. The backup vocabulary may include files that contain user-specific backup vocabulary words and system-wide backup vocabulary words.

User-specific backup vocabulary words include words which a user has created while using the speech recognition software. These words are stored in vocabulary files for the user and for the dictation, and are available as part of the backup dictionary for the dictation topic regardless of user, and to the user regardless of which dictation topic is being used. For example, if a user is using a medical topic and adds the word "ganglion" to the dictation vocabulary, any other user of the medial topic will have immediate access to the word "ganglion". In addition, the word will be written into the user-specific backup vocabulary. Then, if the user says "ganglion" while using a legal topic, the word "ganglion" will be available during correction from the backup dictionary.

In addition to the user-specific backup vocabulary noted above, there is a system-wide backup vocabulary. The system-wide backup vocabulary contains all the words known to the system, including words which may currently be in an active vocabulary.

During error correction, word searches of the backup vocabularies start with the user-specific backup vocabulary and then check the system-wide backup vocabulary. The backup vocabularies also are searched when there are new words in text that a user has typed.

FIG. **4**A illustrates another example of a constraint grammar for a "select" command used to select previously recognized text. As shown, a constraint grammar may be illustrated as a state diagram **400**. The "select" command includes the word "select" followed by one more previously-recognized words, with the words being in the order recognized. The first state **405** of the constraint grammar indicates that the first word of the select command must be "select". After the word "select", the constraint grammar permits a transition along a path **410** to a second state **415** that requires the next word in the command to be a previously-recognized word. A path **420**, which returns to the second state **415**, indicates that the command may include additional previously-recognized words. A path **425**, which exits the second state **415** and completes the command, indicates that the command may include only previously-recognized words. FIG. **4**B illustrates the state diagram **450** of the constraint grammar for the select command when a previously-recognized utterance is "four score and seven". This state diagram could be expanded to include words from additional utterances.

The constraint grammar also may be expressed in Backus-Naur Form (BNF) or Extended BNF (EBNF). In EBNF, the grammar for the "Select" command is:

<recognition result>::=Select <word>, where

<word>::=[PRW^1[PRW^2[PRW^3. . PRW^n]]]¦

[PRW^2[PRW^3. . PRW^n]]¦. . PRW^n,

"PRW^i" is the previously-recognized word i,

[ ] means optional,

< > means a rule,

¦ means an OR function, and

::=means "is defined as" or "is".

As illustrated in FIGS. **4**A and **4**B, this notation indicates that "select" may be followed by any ordered sequence of previously-recognized words. Constraint grammars are discussed further in U.S. patent application Ser. No. 08/559,207, filed Nov. 13, 1995 and entitled "CONTINUOUS

RECOGNITION OF SPEECH AND COMMANDS", which is incorporated by reference.

Other constraint grammars **225** include an in-line dictation macros grammar for dictation commands, such as "Capitalize" to capitalize a word and "New-Paragraph" to start a new paragraph; a select X Y Z grammar used in selecting text, an error correction commands grammar; a dictation editing grammar, an application command and control grammar that may be used to control a particular application program **155**; a global command and control grammar that may be used to control the operating system **150** and the speech recognition software **160**; a menu and dialog tracking grammar that may be used to manipulate menus; and a keyboard control grammar that permits the use of speech in place of input devices, such as the keyboard **115** or the mouse **110**.

Referring again to FIG. **2**, the recognizer **215** may operate in parallel with a pre-filtering procedure **240**. Upon initiating processing of an utterance, the recognizer **215** requests from the pre-filtering procedure **240** a list of words that may have been spoken as the first word of the utterance (i.e., words that may correspond to the first and subsequent frames of the utterance). The pre-filtering procedure **240** performs a coarse comparison of the sequence of frames with the active vocabulary **230** to identify a subset of the vocabulary for which a more extensive comparison using the recognizer is justified.

Referring to FIGS. **5** and **6**, the pre-filtering procedure **240** uses a lexical tree **500** that is initialized before processing begins. The lexical tree represents the active vocabulary **230** based on the phonetic relationships between words in the vocabulary. The lexical tree includes a root node **505** that represents new words entering the lexical tree. From the root node **505**, the tree expands to a group **510** of nodes that correspond to phonemes with which words start. A silence node **512** that represents silence also may be reached from the root node **505**.

Each node in the group **510** represents a phoneme that appears at the beginning of one or more words. For example, in the portion **600** of the lexical tree **500** illustrated in FIG. **6**, a node **610** corresponds to all words in the vocabulary that start with the phoneme "H". Together, the nodes in the group **510** include representations of the starting phoneme of every word in the vocabulary.

The lexical tree continues to expand until it reaches leaf nodes **515** that represent the actual words of the vocabulary. For example, as indicated by the square marker, leaf node **615** of FIG. **6** corresponds to the word "healing". An internal node of the tree also may represent a word of the vocabulary. For example, the node **520** might represent a particular vocabulary word in addition to representing the first two phonemes of other vocabulary words. Similarly, the leaf node **620** of FIG. **6** corresponds to the words "heal" and "heel" while also corresponding to the first three phonemes of the words "heals", "heels" and "healing". Node **620** also illustrates that, since multiple words may have the same phonetic spelling, a leaf node may correspond to more than one word. As illustrated in FIG. **6**, leaf nodes may appear at different levels within the lexical tree. Leaf nodes also may correspond to commands. For example, a leaf node may correspond to the word "select" and to the command "SELECT". As noted above, commands may be associated with particular constraint grammars **225**.

Operation of the pre-filtering procedure **240** is illustrated in FIG. **7**. The pre-filtering procedure begins by retrieving the next frame of parameters for an utterance (step **700**). Immediately after initialization, the next frame will be the first frame for the utterance. Thereafter, the next frame will be the frame following the last frame that was processed by the pre-filtering procedure when the pre-filtering procedure was last called. The pre-filtering procedure does not reinitialize the lexical tree between requests for list of words. Accordingly, the state of the lexical tree when a list of words is requested corresponds to the state of the lexical tree after a previous list of words was returned.

After retrieving a frame of data, the pre-filtering procedure finds an active node in the tree with no unprocessed active successors (step **705**). Successors of a node also may be referred to as subnodes of the node. When the lexical tree is initialized, the silence node **512** is the only active node.

Next, the pre-filtering procedure processes the current node (step **710**) according to a node-processing procedure **1100** that is discussed below with reference to FIG. **11**. The node-processing procedure determines whether the node should spawn additional active nodes and whether the node should be rendered inactive. If the node is a leaf node, the node-processing procedure also determines whether the word corresponding to the node should be added to a word list for a time associated with the node.

After processing the node (step **710**), the pre-filtering procedure determines whether the node is the highest node in the tree (i.e., the root node) (step **715**). If the node is not the highest node, then the pre-filtering procedure goes to the next node having no unprocessed active subnodes (step **720**) and processes that node (step **710**). When searching for the next node to process, the pre-filtering procedure considers inactive nodes having active subnodes or active siblings.

If the processed node is the highest active node (step **715**), then the pre-filtering procedure processes the silence node **512** (step **725**). In general, the silence node is processed by comparing a frame to a model for silence and adding the resulting score to the minimum of the current score for the silence node and the score for the root node **505**.

Next, the pre-filtering procedure reseeds the lexical tree (step **730**). The pre-filtering procedure reseeds the tree whenever the silence node **512** is active or a word was produced by a leaf node of the lexical tree, regardless of whether the word was added to the list of words. The pre-filtering procedure reseeds the tree by replacing the score for the root node **505** with the minimum of the score for the silence node **512** and the scores for any words produced by leaf nodes of the lexical tree for the current frame. If the silence node is inactive and no leaf node has produced a word, then the pre-filtering procedure replaces the score for the root node **505** with a bad score (i.e., a score having a value larger than a pruning threshold).

Next, the pre-filtering procedure determines whether more words may be added to the word list for the requested time (step **735**). If there are no active nodes in the lexical tree corresponding to speech that started at, before, or slightly after the start time for which the list was requested, and if the last frame to be processed corresponds to a time that is slightly after the start time for which the list was requested, then no more words may be added to the word list. A word produced by the lexical tree is added to the list of words corresponding to the start time of the word and to lists of words corresponding to times that precede and follow the start time of the word. It is for this reason that the pre-filtering procedure waits until there are no active nodes in the tree corresponding to speech that started slightly after the start time for the list of words. If more words may be added, then the pre-filtering procedure retrieves the next frame of parameters (step **700**) and repeats the steps discussed above.

If words cannot be added to the word list (step **735**), then the pre-filtering procedure returns the word list (step **740**) to

the recognizer **215**. If the word list includes more than a predefined number of words, then the pre-filtering procedure removes words from the list prior to returning the list. The pre-filtering procedure removes the words that are least likely to correspond to the user's speech and removes enough words to reduce the number of words on the list to the predefined number. The procedure also deletes any lists of words for times prior to the requested start time.

Each node of the lexical tree **500** (FIG. **5**) represents a sequence of states for a particular phoneme. For example, FIG. **8**A illustrates a node **800** that includes a first state **805**, a second state **810**, and a third state **815**. A comparison with a frame of parameters may cause the score in a particular state to remain in the state (through a path **820**). A score remains in the state when the score, after being adjusted based on a comparison with a model for the state, is better than a score passed from a preceding state or node, or when no score is passed from a preceding state or node. The comparison also may cause the score to be passed to a subsequent state through a path **825**. A score is passed to a subsequent state when the score, after being adjusted based on a comparison with a model for the subsequent state, is better than the score in the subsequent state, or when no score is associated with the subsequent state. The score for the third state **815** may be passed to one or more subsequent nodes through a path **830**.

Referring to FIG. **8**B, the node **512** that corresponds to silence is represented by a single state **840**. Each comparison with a frame of parameters may cause a score in the node to remain in the state **840** (through the path **845**) and also may cause the score to be passed to the root node **505** through a path **850**.

Referring to FIG. **8**C, the root node **505** is represented by a single state **860**. Comparison with a frame causes the score in the node to be passed to one or more subsequent nodes (including the silence node **512**) through a path **865**.

Each state of a node may be represented by four values: a score, a starting time, a leaving penalty, and a staying penalty. The score represents the likelihood that a series of frames has placed the lexical tree in the state (i.e., the probability that the series of frames corresponds to the word or portion of a word to which the state corresponds). The scores are maintained as negative logarithmic values.

The starting time identifies the hypothesized time at which the user began to speak the word or words represented by the state. In particular, the starting time identifies the time at which the score associated with the state entered the lexical tree (i.e., the time at which the score was passed from the state **840** along the path **850**).

The leaving and staying penalties are fixed values associated with the state. The staying penalty is added to any score that stays in the state. The staying penalty is related inversely to the length of the sound represented by the state and to the length of the phoneme represented by the node to which the state belongs. For example, the staying penalty could be proportional to $-\log(1-1/d_{avg})$, where d_{avg} is the average duration, in frames, of the sound represented by the state. Thus, the staying penalty has a relatively large value when the sound corresponding to the state occurs for only a small amount of time and a relatively small value when the sound corresponding to the state occurs for a large amount of time.

The leaving penalty is added to any score that exits the state, and includes a duration component and a language model component. The duration component is related directly to the length of the sound represented by the state and to the length of the phoneme represented by the node to

which the state belongs. For example, the duration component of the leaving penalty could be proportional to $-\log(1/d_{avg})$. Thus, the duration component of the leaving penalty has a relatively large value when the sound corresponding to the state occurs for a large amount of time and a relatively small value when the sound corresponding to the state occurs for a small amount of time.

The language model components of the leaving penalties for all states in a particular node together represent a language model score for the phoneme associated with that node. The language model score represents the likelihood that a word including the phoneme will occur in speech. The language model score included in the leaving penalties for a node is the increase in the best language model score for the branch of the lexical tree that begins with the node relative to the branch of the lexical tree that begins with the node's parent.

The following discussion assumes that there are no leaving or staying penalties associated with the state **840** or the state **860**. The same result could be achieved by setting the leaving and staying penalties for states **840** and **860** equal to zero. The following discussion also assumes that the first frame is the first frame that may correspond to speech instead of silence.

FIG. **9** provides a simplified example of how scores propagate through the lexical tree. Before the first frame is retrieved (row **900**), state **840** (which corresponds to silence) has a score of 0 and no other nodes are active. The score of 0 means that there is a one hundred percent probability that the system is starting from silence.

After the first frame is retrieved (row **905**), the score for the state **840** (S_{A1}) is set equal to the acoustic score (A_{A1}) resulting from an acoustic match of the first frame with an acoustic model corresponding to the state **840** (i.e., the acoustic model for silence). Thus, the score for the state **840** (S_{A1}) is set equal to the likelihood that the first frame corresponds to silence.

Retrieval of the first frame also causes the state **805** to become an active state. Assuming that the node **800** corresponds to a phoneme that starts a word, the score for the state **805** (S_{B1}) is set equal to the acoustic score (A_{B1}) resulting from an acoustic match of the first frame with the acoustic model corresponding to the state **805**. Thus, the score for the state **805** (S_{B1}) is set equal to the likelihood that the first frame corresponds to the state **805**. The starting time for the state **805** is set equal the time associated with the first frame. This value for the starting time indicates that the score at state **805** represents a word that started at a time corresponding to the first frame. The starting time moves with the score as the score propagates through the lexical tree.

After the second frame is retrieved (row **910**), the score for the state **840** (S_{A2}) is set equal to the sum of the previous score for the state (S_{A1}) and the acoustic score (A_{A2}) resulting from an acoustic match of the second frame with the acoustic model for silence:

$$S_{A2}=S_{A1}+A_{A2}=A_{A1}+A_{A2}.$$

As noted above, each of the scores corresponds to a negative logarithmic probability. Accordingly, adding scores together corresponds to multiplying the probabilities. Thus, the score for the state **840** (S_{A2}) equals the likelihood that both of the first and second frames correspond to silence. This process is repeated for subsequent frames (e.g., lines **915** and **920**) so that the score for the state **840** at a frame "n" (S_{An}) equals:

$$S_{An} = S_{An-1} + A_{An} = \sum_{m=1}^{n} A_{Am}.$$

This expression assumes that the silence node **512** is not reseeded from the root node **505**. If reseeding occurs at a frame n, then the value of S_{An-1} would be replaced by the score in the root node **505** for the frame n−1.

After the second frame is retrieved, the score for the state **805** (S_{B2}) is set equal to:

$$S_{B2}=\min(S_{B1}+\text{stay}_B, S_{A1})+A_{B2},$$

where A_{B2} is the acoustic score resulting from an acoustic match of the second frame with the acoustic model corresponding to state **805** and stay_B is the staying penalty for state **805**. The score for state **805** (S_{B2}) corresponds to the more likely of two alternatives: (1) the first frame was silence and the second frame was the sound represented by the state **805** or (2) both of the first and second frames were the sound represented by the state **805**. The first alternative corresponds to a transition from state **840** to state **805** along the path **850**. The second alternative corresponds to a transition from state **805** back to state **805** along path **820**. When the first alternative is the more likely, the starting time corresponding to the first frame that was stored previously for the state **805** is replaced by a value corresponding to the second frame. This value indicates that the score at state **805** represents a word that started with the second frame.

After the second frame is retrieved, the state **810** becomes an active state. The score for the state **810** (S_{C2}) is set equal to:

$$S_{C2}=S_{B1}+\text{leave}_B+A_{C2},$$

where A_{C2} is the acoustic score resulting from an acoustic match of the second frame with the acoustic model corresponding to state **810** and leave_B is the leaving penalty for the state **805**. Similarly, leave_C and leave_D are leaving penalties for, respectively, states **810** and **815**. The sum of language model components of leave_B, leave_C and leave_D represents the language model score for the phoneme represented by the node **800**.

The methodology for determining state scores for states other than the silence state can be expressed more generally as:

$$S_{i,j}=\min(S_{i,j-1}+\text{stay}_i, S_{i-1,j-1}+\text{leave}_{j-1})+A_{i,j}.$$

for i greater than zero (where i equals zero corresponds to silence), and with the boundary condition that the score for an inactive state equals infinity or some sufficiently large value. The starting time for the state may be represented as:

$$t_{i,j}=t_{i,j-1} \text{ for } S_{i,j-1}+\text{stay}_i \leqq Si-1,j-1+\text{leave}_{j-1},$$

or

$$t_{i,j}=t_{i-1,j-1} \text{ for } S_{i,j-1}+\text{stay}_i < Si-1,j-1+\text{leave}_{j-1},$$

for i and j greater than zero and with the boundary condition that the time value for a newly active state represents the frame at which the state became active. As previously noted, state scores for the silence state may be determined as:

$$S_{0,j} = S_{0,j-1} + A_{0,j} = \sum_{m=1}^{j} A_{0,m}.$$

with the boundary condition that $S_{0,0}$ equals zero. An even more general form, in which the scores are expressed as functions of the various parameters, is illustrated in FIG. **10**.

Referring to FIG. **11**, a node may be processed according to a node-processing procedure **1100**. Initially, the node-processing procedure updates the scores and time values for each state of the node (step **1105**). The node-processing procedure updates the scores and time values by generating acoustic scores and using the equations discussed above.

When the last state of the node was active prior to updating the scores for the node, the node-processing procedure uses the score for the last state to generate scores for any inactive subnodes of the node. If the generated score for a subnode does not exceed a pruning threshold, then the node-processing procedure activates that subnode and provides the subnode with the generated score.

Next, the node-processing procedure determines whether the score of any state of the node exceeds the pruning threshold (step **1110**). When a score exceeds the pruning threshold, the likelihood that the word represented by the score was spoken is deemed to be too small to merit further consideration. For this reason, the procedure prunes the lexical tree by deactivating any state having a score that exceeds the pruning threshold (step **1115**). If every state of the node is deactivated, then the node-processing procedure also deactivates the node. The node-processing procedure may deactivate a node or state by deleting a record associated with the node or state, or by indicating in the record that the node or state is inactive. Similarly, the node-processing procedure may activate a node or state by creating a record and associating the record with the node or state, or by indicating in an existing record that the node or state is active. The procedure may use a dynamic pruning threshold that accounts for variations in the average or best score in the lexical tree at any given time.

Next, the node-processing procedure determines whether a word is to be added to a list of words (step **1120**). A word is added to the list of words when the node being processed corresponds to the last phoneme of a word, a score has been propagated out of the last state of the node, and the score is less than a list threshold. Before comparing the score to the list threshold, the node-processing procedure adds a language model score to the score. The language model score corresponds to the difference between the language model score for the word and the incremental language model score that is already included in the score. In general, the list threshold has a lower value than the pruning threshold. If the node being processed corresponds to the last phoneme of multiple words having the same phonetic spelling, then all of the words to which the node corresponds are added to the list of words.

If the noted conditions are met, the node-processing procedure adds the word or words to the list (step **1125**). A word is stored in the list of words along with the score propagated out of the last state. If the word is on the list already, then the node-processing procedure stores with the list the better of the score already stored with the list or the score propagated out of the last state. The scores for words in a list of words are returned along with the list of words. The recognizer **215** uses these scores in making the detailed match.

The node-processing procedure also adds the word to lists of words for times that precede or follow the starting time to

account for possible inaccuracies in the starting time of the word that may result from selecting the better of a score that remains in a state or a score propagated from a prior state. Spreading the word across multiple lists ensures that these inaccuracies will not impinge on the accuracy of the speech recognition system. The node-processing procedure spreads the word across multiple lists based on the length of the word.

After adding a word to the list of words (step **1125**), the node-processing procedure saves the score associated with the word as a reseeding score for use in reseeding the tree (step **1130**). Production of a word by the lexical tree means that the current frame may correspond to the last frame of the word (with the probability of such a correspondence being reflected by the score associated with the word). This means that the next frame may correspond to the beginning of a word or to silence resulting from a pause between words. The pre-filtering procedure reseeds the tree (step **730** of FIG. **7**) to account for this possibility.

For a given frame, multiple nodes may produce words. However, the tree only needs to be reseeded once. To account for this, the node-processing procedure only saves the score associated with a word (S_w) as the reseeding score (S_{RS}) if the word is the first word to be generated by the tree for the current frame of if the word score is less than the score for all other words generated by previously-processed nodes for the current frame (S_{RS}'):

$$S_{RS}=\min(S_w, S_{RS}').$$

Saving only the lowest score (i.e., the score indicating the highest probability that the current frame was the last frame of a word) ensures that the tree will be reseeded using the highest probability that the next frame is the first frame of a new word.

To reseed the tree (step **730** of FIG. **7**), the pre-filtering procedure activates the root node **505** and associates the minimum of the reseeding score (S_{RS}) and the score for the silence node **512** with the root node. During processing of the next frame, the active root node **505** may be used to activate nodes in the group **510** or to activate the silence node **512**.

Processing of the node is complete after the node-processing procedure saves a score for use in reseeding the tree (step **1130**), or if no word is to be added to the list of words (step **1120**). The lexical tree pre-filtering procedure is discussed in detail in U.S. patent application Ser. No. 08/701,393, filed on Aug. 22, 1996 and entitled "LEXICAL TREE PRE-FILTERING IN SPEECH RECOGNITION", which is incorporated by reference.

After the pre-filtering procedure responds with the requested list of words, the recognizer initiates a hypothesis for each word from the list and compares acoustic models for the word to the frames of parameters representing the utterance. The recognizer uses the results of these comparisons to generate scores for the hypotheses. Hypotheses having excessive scores are eliminated from further consideration. As noted above, hypotheses that comply with no active constraint grammar also are eliminated.

When the recognizer determines that a word of a hypothesis has ended, the recognizer requests from the pre-filtering procedure a list of words that may have been spoken just after the ending-time of the word. The recognizer then generates a new hypotheses for each word on the list, where the old hypothesis plus the new words of the old hypothesis plus the new word.

In generating the score for a hypothesis, the recognizer uses acoustic scores for words of the hypothesis, a language model score that indicates the likelihood that words of the hypothesis are used together, and scores provided for each word of the hypothesis by the pre-filtering procedure. The scores provided by the pre-filtering procedure include components corresponding to a crude acoustic comparison and a language model score indicative of the likelihood that a word is used, independently of context. The recognizer may eliminate any hypothesis that is associated with a constraint grammar (e.g., a command hypothesis), but does not comply with the constraint grammar.

Referring to FIG. **12**, the recognizer **215** operates according to a procedure **1200**. First, prior to processing, the recognizer **215** initializes the lexical tree **500** as described above (step **1205**). The recognizer **215** then retrieves a frame of parameters (step **1210**) and determines whether there are hypotheses to be considered for the frame (step **1215**). The first frame always corresponds to silence so that there are no hypotheses to be considered for the first frame.

If hypotheses need to be considered for the frame (step **1215**), the recognizer **215** goes to the first hypothesis (step **1220**). The recognizer then compares the frame to acoustic models **235** for the last word of the hypothesis (step **1225**) and, based on the comparison, updates a score associated with the hypothesis (step **1230**).

After updating the score (step **1230**), the recognizer determines whether the user was likely to have spoken the word or words corresponding to the hypothesis (step **1235**). The recognizer makes this determination by comparing the current score for the hypothesis to a threshold value. If the score exceeds the threshold value, then the recognizer **215** determines that the hypothesis is too unlikely to merit further consideration and deletes the hypothesis (step **1240**).

If the recognizer determines that the word or words corresponding to the hypothesis were likely to have been spoken by the user, then the recognizer determines whether the last word of the hypothesis is ending (step **1245**). The recognizer determines that a word is ending when the frame corresponds to the last component of the model for the word. If the recognizer determines that a word is ending (step **1245**), the recognizer sets a flag that indicates that the next frame may correspond to the beginning of a word (step **1250**).

If there are additional hypotheses to be considered for the frame (step **1255**), then the recognizer selects the next hypothesis (step **1260**) and repeats the comparison (step **1225**) and other steps. If there are no more hypotheses to be considered for the frame (step **1255**), then the recognizer determines whether there are more frames to be considered for the utterance (step **1265**). The recognizer determines that there are more frames to be considered when two conditions are met. First, more frames must be available. Second, the best scoring node for the current frame or for one or more of a predetermined number of immediately preceding frames must have been a node other than the silence node (i.e., the utterance has ended when the silence node is the best scoring node for the current frame and for a predetermined number of consecutive preceding frames).

If there are more frames to be considered (step **1265**) and the flag indicating that a word has ended is set (step **1270**), or if there were no hypotheses to be considered for the frame (step **1215**), then the recognizer requests from the pre-filtering procedure **240** a list of words that may start with the next frame (step **1275**).

Upon receiving the list of words from the pre-filtering procedure, the recognizer uses the list of words to create hypotheses or to expand any hypothesis for which a word has ended (step **1280**). Each word in the list of words has an

associated score. Prior to adding a list word to a hypothesis, the recognizer modifies the list score (S_L) for the word to produce a modified list score (S_{ML}) as:

$$S_{ML}=S_L+L_C-L_L,$$

where L_C is a language model score that represents the frequency with which the pair of words that includes the list word and the immediately preceding word in the hypothesis are used together in speech, and L_L is a language model score included in the list score and corresponds to the frequency with which the list word is used in speech, without reference to context. The recognizer then adds the modified list score to the score for the hypothesis and compares the result to a threshold value. If the result is less than the threshold value, then the recognizer maintains the hypothesis. Otherwise, the recognizer determines that the hypothesis does not merit further consideration and abandons the hypothesis. As an additional part of creating or expanding the hypotheses, the recognizer compares the hypotheses to the active constraint grammars **225** and abandons any hypothesis that corresponds to no active constraint grammar. The recognizer then retrieves the next frame (step **1210**) and repeats the procedure.

If there are no more speech frames to process, then the recognizer **215** provides the most likely hypotheses to the control/interface module **220** as recognition candidates (step **1285**).

The control/interface module **215** controls operation of the speech recognition software and provides an interface to other software or to the user. The control/interface module receives the list of recognition candidates for each utterance from the recognizer. Recognition candidates may correspond to dictated text, speech recognition commands, or external commands. When the best-scoring recognition candidate corresponds to dictated text, the control/interface module provides the text to an active application, such as a word processor. The control/interface module also may display the best-scoring recognition candidate to the user through a graphical user interface. The control/interface module controls operation of the speech recognition software in response to speech recognition commands (e.g., "wake up", "make that"), and forwards external commands to the appropriate software.

The control/interface module also controls the active vocabulary, acoustic models, and constraint grammars that are used by the recognizer. For example, when the speech recognition software is being used in conjunction with a particular application (e.g., Microsoft Word), the control/interface module updates the active vocabulary to include command words associated with that application and activates constraint grammars associated with the application.

Other functions provided by the control/interface module **220** include a vocabulary customizer and a vocabulary manager. The vocabulary customizer optimizes the language model of a specific topic by scanning user supplied text. The vocabulary manager is a developer tool which is used to browse and manipulate vocabularies, grammars and macros. Each such function of the control/interface module **220** may be implemented as an executable program that is separate from the main speech recognition software. Similarly, the control/interface module **220** also may be implemented as a separate executable program.

The control/interface module **220** also may provide an enrollment program that uses an enrollment text and a corresponding enrollment grammar to customize the speech recognition software to a specific user. Specifically, as a user reads the enrollment text, the recognizer **215** uses the enrollment grammar to match a sequence of utterances by the user to sequential portions of the enrollment text and uses acoustic information from the user's utterances to train or adapt acoustic models **235** corresponding to the matched portions of the enrollment text.

The enrollment program may provide a list of enrollment texts, each of which has a corresponding enrollment grammar, for the user's selection. Alternatively, the user may input an enrollment text from another source. In this case, the enrollment program may generate the enrollment grammar from the input enrollment text, or may employ a previously generated enrollment grammar.

FIG. **13** shows a user interface **1300** of the enrollment program. The user interface **1300** displays an enrollment text **1310** for the user to read and displays the user's current position, also referred to as the "enrollment position", using, for example, a moving arrow **1320** in the enrollment text. For example, the display of FIG. **13** shows an enrollment position at the word "for", indicating that the enrollment program has recognized the user's reading of the enrollment text up to the word "for" and that the enrollment process will continue when the user continues reading, beginning with the word "for". By contrast, the display of FIG. **14** indicates an enrollment position at the word "program".

Using the user interface **1300** of FIG. **13**, the user starts the enrollment program by selecting the Record button **1330** through a voiced command or an input device such as a mouse. The user then reads the displayed text **1310** beginning with the text at the enrollment position, as indicated by the arrow **1320**. As the user reads, the recognizer **215** matches the user's speech to the enrollment text using the enrollment grammar and advances the enrollment position (and arrow **1320**) to the beginning of the next word to be spoken. Acoustic models corresponding to the enrollment text are updated based on the matching user utterances. In general, the recognizer **215** does not use the pre-filtering procedure **240** during the enrollment process.

As shown in FIG. **15**, the enrollment program begins by setting the enrollment position at the beginning of the enrollment text (step **1510**) and displaying the arrow at the enrollment position (step **1520**). The enrollment program next receives the user's digitized speech for an utterance (step **1530**). The recognizer **215**, using the enrollment grammar corresponding to the enrollment text, determines whether the utterance matches a portion of the enrollment text beginning at the enrollment position (step **1540**). Because the portion of the text to which an utterance corresponds is unspecified, the recognizer **215** uses the enrollment grammar to identify a portion of the enrollment text beginning at the enrollment position that best matches the utterance.

If there is no match, the enrollment program repeats the process of retrieving and comparing the user's speech with the enrollment text (steps **1530**, **1540**). If there is a match, the enrollment program updates the acoustic models **235** corresponding to the matched portion of the enrollment text based on the user utterance (step **1550**). Alternatively, the enrollment program may update the acoustic models after specific segments (such as sentences or paragraphs) of enrollment text have been recognized, or after the entire enrollment text have been recognized.

If no enrollment text remains after the matched portion of enrollment text (step **1560**), the enrollment program for that enrollment text ends (step **1570**). If the enrollment program provides multiple enrollment texts, after finishing one enrollment text, the enrollment program may automatically begin the next enrollment text by displaying the new enroll-

ment text and setting the enrollment position at the beginning of that new text (step **1510**).

If enrollment text remains at step **1560**, the enrollment position is advanced to the word following the matched portion of the enrollment text (step **1580**), the arrow display is updated to point to the updated enrollment position (step **1520**), and the enrollment process continues.

Different methods may be used to determine whether a user utterance matches a portion of the enrollment text (step **1540**). For example, the enrollment grammar may be implemented to recognize that different users may pause at different positions in the enrollment text, with the result that utterances of different users may not uniformly correspond to the same portion of the enrollment text. As noted above, the enrollment grammar may handle such situations by allowing different lengths of enrollment text to match a user's utterance.

The enrollment grammar may be implemented to recognize and appropriately handle expected variations in the user's reading of the enrollment text in determining whether a user utterance matches a portion of the enrollment text. An example of such a variation is the dictation convention of enunciating punctuation marks: at the end of sentence, the user may enunciate the word "period". To handle this situation, the enrollment grammar may be implemented to recognize the word "period" at the end of sentences as optional. Thus, if the user says "period", the enrollment grammar matches the user's speech to the word period for purposes of updating the acoustic models. If the user does not say period, the enrollment grammar skips the optional word "period" to the next word in the enrollment text.

Similar rules may be implemented for handling user enunciation of spacing (e.g., new line or new paragraph), and formatting conventions (e.g., capitalization, bold, underline, or italics). For example, the enrollment grammar for the passage of text illustrated in FIG. **13** may be expressed in EBNF as:

<recognition result>::=[Capitalize] dragon [Capitalize] systems is pleased to acknowledge [Capitalize] arthur [Capitalize] c [Period] [Capitalize] clarke and [Capitalize] harper [Capitalize] collins [Capitalize] publishers for allowing us to use selections from [Capitalize] arthur [Capitalize] c [Period] [Capitalize] {clarke's ¦ clarke Apostrophe s} novel three thousand [and] one [Colon] [Capitalize] the [Capitalize] final [Capitalize] odyssey [Comma] for our training program [Period]

The enrollment grammar is modified as the user advances through the text. For example, when the user is at the word "for" in the text, as indicated by the arrow **1320** in FIG. **13**, the enrollment grammar may be expressed in EBNF as:

<recognition result>::=for our training program [Period]

Alternatively, the enrollment grammar may be expressed as a set of rules. Appendix A includes a possible rule-based grammar for the enrollment text shown in FIG. **13**. An advantage of the ruled-based grammar is that it does not need to be modified as the user advances through the text.

In general, the enrollment program reduces the recognition error rate of the speech recognition system by customizing user-independent acoustic models to a user's speech based on the user's pronunciation of sounds corresponding to those acoustic models in reciting the enrollment text. However, if the user says something other than the expected enrollment text, the user's speech should not be used to update the acoustic models corresponding to the expected enrollment text. This situation may arise, for example, if the user skips a line in the displayed text **1310**, mistakenly reads a displayed word as a different word, or is interrupted while reading the displayed text and engages in an outside conversation. This situation also may arise if the speech recognition system picks up sounds other than the user's speech, such as a cough or sneeze, or environmental noise such as traffic or a barking dog.

The enrollment grammar permits the recognizer **215** to find the portion of the enrollment text that best corresponds to the user's utterance. However, the enrollment grammar does not permit the recognizer **215** to verify that the utterance actually corresponds to the enrollment text. For this purpose, the enrollment program uses a rejection grammar in conjunction with the enrollment grammar to identify situations in which the sound detected by the recognizer does not match the expected enrollment text.

FIG. **16** elaborates the process of step **1540** of FIG. **15**, where both the enrollment grammar and the rejection grammar are used to detect situations in which the user utterance should not be used to update the acoustic models for enrollment text. The enrollment program identifies a best recognition candidate that corresponds to the enrollment grammar and designates the score provided by the recognizer **215** for that candidate as the enrollment score (step **1541**). The recognizer **215** may determine the score for the candidate based on criteria, such as matching acoustic models and word context.

Even the best recognition candidate may not be a good match to the enrollment text. For example, if the enrollment position is at "for", as shown in FIG. **13**, and the user utterance is "from Arthur C. Clarke's novel" from the previous line, the recognizer **215** will attempt to match the utterance to the portion of the enrollment grammar starting with "for", and will produce a recognition candidate corresponding to the best match to that portion of the enrollment grammar.

The enrollment program also identifies a best recognition candidate that corresponds to the rejection grammar and designates a score provided by the recognizer **215** for that candidate as a rejection score (step **1542**). In general, the rejection score should be better than the enrollment score when the user utterance does not correspond to the expected portion of the enrollment text.

The rejection grammar may be expressed in EBNF as:

<recognition result>::=<phonemes>

where

<phonemes>::=phoneme[<phonemes>]

and phoneme is any phoneme in a rejection grammar phoneme set. The rejection grammar phoneme set is selected such that most sounds in the expected speech can be reasonably modeled. If, as in the above example, the rejection grammar allows any combination of these phonemes, the processing required to find the best matching phonemes for an utterance can be expensive. Accordingly, the rejection grammar phoneme set may include only a subset of the set of phonemes used by the speech recognition. For example, the attached Appendix B illustrates a set of fifty phonemes, with a subset of 19 of the phonemes being included in the rejection grammar phoneme set.

The rejection grammar matches the acoustics of the user utterance to a sequence of phonemes from the rejection grammar phoneme set. The score associated with a rejection grammar recognition candidate reflects the degree to which the user utterance corresponds to the matched sequence of

phonemes and is determined so that the rejection score is likely to be better than the enrollment score when the user utterance does not match a portion of the enrollment text.

Again referring to the above example of FIG. **13**, in which the enrollment position is at "for" and the user utterance is "from Arthur C. Clarke's novel", the enrollment grammar will likely result in a recognition candidate with a score reflecting a poor match. On the other hand, the rejection grammar will result in a recognition candidate that may not be "from Arthur C. Clarke's novel" exactly, but will likely be closer than the enrollment recognition candidate beginning with "for". Accordingly, the rejection grammar should result in a recognition candidate having a better match and a better score.

The enrollment program determines whether the user utterance matches an enrollment utterance by comparing the enrollment score to the rejection score (step **1543**). The precise method of comparison may vary. For example, in a simple approach, the enrollment program compares the enrollment and rejection scores and, if the enrollment score is better than the rejection score, determines that the user utterance matches a portion of the enrollment text (step **1544**). Alternatively, if the rejection score is better than the enrollment score, as in the above example, the enrollment program determines that the user utterance does not match a portion of the enrollment text (step **1545**).

The rejection grammar has been described with reference to its use with the enrollment grammar. However, it also may be used in other circumstances, and, in general, is used whenever the large vocabulary dictation constraint grammar is not active. For example, the speech recognition software may include a "Go To Sleep" command that deactivates all constraint grammars except the rejection grammar and a grammar for recognizing a "Wake Up" command. In general, after the "Go To Sleep" command has been implemented, the recognizer **215** will recognize only the "Wake Up" command. The rejection grammar enables the control/interface module **220** to distinguish between the "Wake Up" command and noise or other sounds.

The enrollment program creates a speaker-adapted model for the user by adapting speaker-independent acoustic models corresponding to the enrollment text based on the user's utterances. As described above, the speaker-independent acoustic models represent each triphone node as a mixture of Gaussian probability density functions("PDFs") N_k having mean vectors μ_k and covariance matrices C_k, with the contribution made to the triphone node by each PDF being represented by a mixture weight w_k. The speaker-adapted model uses the mixture weights w_k and the covariance matrices c_k of the speaker-independent model, but uses adapted mean vectors μ_{kA}.

Referring to FIG. **17**, the enrollment program generates the adapted mean vectors μ_{kA} according to a procedure **1700**. Starting with the mean vectors μ_k of the speaker-independent (step **1705**), the enrollment program uses a transformation-based approach to produce the adapted mean vectors μ_{kA}. The transformation-based approach assumes that an adapted mean vector μ_{kA} may be expressed as:

$$\mu_{kA}=A\mu_k+b,$$

where A and b are transforms. When each mean vector has 24 entries, A is a 24×24 matrix and b has 24 entries.

Next, the enrollment program generates collections of PDFs that are expected to share a common transformation (step **1710**). A collection C could include the PDFs representing similarly-sounding triphones, such as all PDFs associated with vowels or all PDFs associated with consonants.

Another approach to generating collections is to group PDFs having mean vectors μ_k with similar values. This approach permits simplified generation of large numbers of collections. In general, implementations may include from one to several hundred different collections. Initial experimental results indicate that the first approach provides better results (i.e, results with lower recognition error rates). In general, the collections may be identified prior to the enrollment session.

Next, for each collection, the enrollment program assembles all speaker data for the PDFs included in the collection (step **1715**). This speaker data corresponds to the user utterances produced during the enrollment session.

Next, the enrollment program determines y[j], the average value of the speaker data vector, for each PDF j (step **1720**). If f[n] is the vector for the n-th frame of speaker data, $p_j(n)$ is the probability that the n-th frame of speaker data corresponds to a PDF j (i.e., the mixture weight w_j for the triphone node associated with the n-th frame of speaker data), and N is the total number of frames of speaker data, then y[j] and the frame count, N[j], for the frame j may be determined as:

$$y[j]=\left(\sum_{n=1}^{N}p_j(n)\right)^{-1}\sum_{n=1}^{N}p_j(n)f[n],$$

$$N[j]=\sum_{n=1}^{N}p_j(n).$$

This is usually referred to as the Baum-Welch or EM algorithm.

Next, the enrollment program produces transforms (A_C and b_C) for each collection C using the relationship between the average values of the speaker data and the PDFs from the speaker-independent model (step **1725**). This relationship may be expressed generally as:

$$y[j]=A_Cx[b]+b_C+e,$$

where x[j] corresponds to the mean vector μ_j for a PDF j and e is an error term. Based on this relationship, A_C^T, the transpose of the transform A_C, may be determined as:

$$A_C^T=\left(\sum_{j=1}^{N_C}N(j)x[j]x^T[j]\right)^{-1}\sum_{j=1}^{N_C}N(j)x[j]y^T[j],$$

where $x^T[b]$ is the transpose of x[j], $y^T[j]$ is the transpose of y[j], and N_C is the number of components in the collection C.

The transform A_C is then produced by transposing A_C^T, and the transform b_C is determined as:

$$b_C=\left(\sum_{j=1}^{N_C}N(j)\right)^{-1}\sum_{j=1}^{N_C}N(j)(y[j]-A_Cx[j]).$$

Using the transforms, the enrollment program determines adapted mean vectors, μ_{jA}, for each component in the collection C (step **1730**). In particular, the adapted mean vectors are determined as:

$$\mu_{jA}=A_C\mu_j+b_C.$$

The enrollment program then stores the adapted mean vectors μ_{jA} along with a speaker-identifier as a speaker-

adapted model for later use in recognizing speech by the user (step **1735**). This process may be iterated several times by using the adapted models to update the frame counts, speaker (N[j] and y[j]), and the transform matrix.

In another implementation, fractions of the speaker independent means (x[j]) and the speaker-specific means may be used to compute y[j] and N[j]:

$$y[j] = \left(r + \sum_{n=1}^{N} p_j(n) \right)^{-1} \left(\sum_{n=1}^{N} p_j(n) f[n] + r x[j] \right)$$

$$N[j] = r + \sum_{n=1}^{N} p_j(n)$$

where r controls the relative importance of the speaker-independent means and the observed data. The value of r is optimized as a function of the amount of the adaptation data available.

Other embodiments are within the scope of the following claims. For example, an enrollment program may include multiple enrollment texts, each with corresponding enrollment grammars, allowing a user to select one or more texts for enrollment. The user may create an enrollment text, for which the enrollment program will create a corresponding enrollment grammar. The specific methods by which the enrollment and rejection grammars score a user utterance may vary. Similarly, the method by which the scores are evaluated to determine whether the user utterance matches a portion of the enrollment text may vary.

The user interface may display the enrollment position using various techniques. For example, in addition to the arrow discussed above and shown in the figures, possibilities include highlighting portions of the text as they are recognized or displaying a cursor at the enrollment position.

The techniques described here are not limited to any particular hardware or software configuration; they may find applicability in any computing or processing environment that may be used for speech recognition. The techniques may be implemented in hardware or software, or a combination of the two. Preferably, the techniques are implemented in computer programs executing on programmable computers that each include a processor, a storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and one or more output devices. Program code is applied to data entered using the input device to perform the functions described and to generate output information. The output information is applied to one or more output devices.

Each program is preferably implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the programs can be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language.

Each such computer program is preferably stored on a storage medium or device (e.g., CD-ROM, hard disk or magnetic diskette) that is readable by a general or special purpose programmable computer for configuring and operating the computer when the storage medium or device is read by the computer to perform the procedures described in this document. The system may also be considered to be implemented as a computer-readable storage medium, configured with a computer program, where the storage medium so configured causes a computer to operate in a specific and predefined manner.

APPENDIX A & B
TO
APPLICATION
FOR
UNITED STATES LETTERS PATENT

TITLE: ENROLLMENT IN SPEECH RECOGNITION
APPLICANT: STEFAN SHERWOOD, TOFFEE ALBINA, DAVID WALD, NOAH GRAHAM, JOEL GOULD AND FRANCESCO SCATTONE

Appendix A

Follows is an enrollment grammar for the paragraph used for examples in the patent document (the rule that is initially activated in this example is AltList0):

```
rule0=Dragon [ <rule1> ]
rule1=systems [ (AftAlt1> ]
rule2=dragon [ <rule3> ]
rule3=systems [ <AftAlt1> ]
rule4=Dragon Systems [ <AftAlt1> ]
AltList0=<rule0> | <rule2> | <rule4>
AftAlt1=is [ <rule7> ]
rule7=please [ <rule8> ]
rule8=to [ <rule9> ]
rule9=acknowledge [ <rule10> ]
rule10=Arthur [ <AltList2> ]
rule11=C. [ <AftAlt3> ]
rule12=[ C\carbon ] [<rule13> ]
rule13=[ .\dot ] [ <AftAlt3> ]
rule14=[ C\carbon ] [ <rule15> ]
rule15=[ .\period ] [ <AftAlt3> ]
rule16=[ C\carbon ] [ <rule17> ]
rule17=[ .\point ] [ <AftAlt3> ]
rule18=[ c\charlie ] [ <rule19> ]
rule19=[ .\dot ] [ <AftAlt3> ]
rule20=[ c\charlie ] [ <rule21> ]
rule21=[ .\period ] [ <AftAlt3> ]
rule22=[ c\charlie ] [ <rule23> ]
rule23=[ .\point ] [ <AftAlt3> ]
rule24=[ C\Roman one hundred ] [ <rule25> ]
rule25=[ .\dot ] [ <AftAlt3> ]
rule26=[ C\Roman one hundred ] [ <rule27> ]
rule27=[ .\period ] [ <AftAlt3> ]
rule28=[ C\Roman one hundred ] [ <rule29> ]
rule29=[ .\point ] [ <AftAlt3> ]
AltList2=<rule11> | <rule12> | <rule14> | <rule16> | <rule18> | <rule20>
| <rule22> | <rule24> | <rule26> | <rule28>
AftAlt3=Clarke [ <rule32> ]
rule32=and [ <AltList4> ]
rule33=harper [ <AftAlt5> ]
rule34=Harper [ <AftAlt5> ]
AltList4=<rule33>] | <rule34>
AftAlt5=Collins [ <rule37> ]
rule37=publishers [ <rule38> ]
rule38=for [ <rule39> ]
rule39=allowing [ <rule40> ]
rule40=us [ <rule41> ]
rule41=to [ <rule42> ]
rule42=use [ <rule43> ]
rule43=selections [ <rule44> ]
rule44=from [ <rule45> ]
rule45=Arthur [ <AltList6> ]
rule46=C. [ <AftAlt7> ]
rule47=[ C\carbon ] [ <rule48> ]
rule48=[ .\dot ] [ <AftAlt7> ]
rule49=[ C\carbon ] [ <rule50> ]
rule50=[ .\period ] [ <AftAlt7> ]
rule51=[ C\carbon ] [ <rule52> ]
rule52=[ .\point ] [ <AftAlt7> ]
rule53=[ c\charlie ] [ <rule54> ]
rule54=[ .\dot ] [ <AftAlt7> ]
rule55=[ c\charlie ] [ <ruleS6> ]
rule56=[ .\period ] [ <AftAlt7> ]
rule57=[ c\charlle ] [ <rule38> ]
rule58=[ .\point ] [ <AftAlt7> ]
rule59=[ C\Roman one hundred ] [ <rule60> ]
rule60=[ .\dot ] [ <AftAlt7> ]
rule61=[ C\Roman one hundred ] [ <rule62> ]
```

-continued

```
rule62=[ .\period ] [ <AftAlt7> ]
rule63=[ C\Roman one hundred ] [ <rule64> ]
rule64=[ .\point ] [ <AftAlt7> ]
AltList6=<rule46> | <rule47> | <rule49> | <rule51> | <rule53> | <rule55>
| <rule57> | <rule59> | <rule61> | <rule63>
AftAlt7=Clarke [ <AltList8> ]
rule67=[ 's\apostrophe-ess ] [ <AftAlt9> ]
rule68=[ 's\iz\r ] [ <AftAlt9> ]
rule69=[ 's\s\r ] [ <AftAlt9> ]
rule70=[ 's\z\r ] [ <AftAlt9> ]
rule71=[ 's\apostrophe ] [ <rule72> ]
rule72=[ s\sierra ] [ <AftAlt9> ]
rule73=[ '\close-single-quote ] [ <rule74> ]
rule74=[ s\sierra ] [ <AftAlt9> ]
rule75=[ '\open-single-quote ] [ <rule76> ]
rule76=[ s\sierra ] [ <AftAlt9> ]
AltList8=<rule67> | <AftAlt9> | <rule68> | <rule69> | <rule70> |
<rule71> | <rule73> | <rule75>
AftAlt9=novel [ <AltList10> ]
rule79=3001 [ <AftAlt11> ]
rule80=30 [ <rule81> ]
rule81=01 [ <AftAlt11> ]
rule82=30 [ <rule83> ]
rule83=0 [ <rule84> ]
rule84=1 [ <AftAlt11> ]
rule85=3 [ <rule86> ]
rule86=0 [ <rule87> ]
rule87=01 [ <AftAlt11> ]
rule88=3 [ <rule89> ]
rule89=0 [ <rule90> ]
rule90=0 [ <rule91> ]
rule91=1 [ <AftAlt11> ]
AltList10=<rule79> | <rule80> | <rule82> | <rule85> | <rule88>
rule93=[ :\colon ] [ <AftAlt13> ]
rule94=[ :\numeric-colon ] [ <AftAlt13> ]
AftAlt11=<rule93> | <AftAlt13> | <rule94>
AftAlt13=the [ <rule97> ]
rule97=final [ <AltList14> ]
rule98=odyssey [ <AftAlt15> ]
rule99=Odyssey [ <AftAlt15> ]
AltList14=<rule98> | <rule99>
rule101=[ ,\comma ] [ <AftAlt17> ]
rule102=[ ,\numeric-comma ] [ <AftAlt17> ]
AftAlt15=<rule101> | <AftAlt17> | <rule102>
AftAlt17=for [ <rule105> ]
rule105=our [ <rule106> ]
rule106=training [ <rule107> ]
rule107=program [ <AltList18> ]
rule108=[ .\dot ] [ <AftAlt19> ]
rule109=[ .\period ] [ <AftAlt19> ]
rule110=[ .\point ] [ <AftAlt19> ]
AltList18=<rule108> | <AftAlt19> | <rule109> | <rule110>
AftAlt19=
```

Appendix B

The phoneme label in the first column is pronounced as the capitalized letter(s) in the second field. The phonemes that have a star in the third field are in the subset of 19 used for the rejection grammar.

b	Baby	
d	Did	
f	Fife	*
g	Gag	*
h	He	*
j	Jay	
k	Kick	*
l	Lily	*
m	Mummy	
n	None	*
p	Pop	
r	Rear	*
s	Sissy	*
t	Tot	*
v	Vivid	*
w	We	*
y	You	*
z	Zoo	
ch	CHip	*
dh	This	
ng	siNG	
sh	SHip	*
th	THin	
zh	measure	
L	middLE	
M	bottOM	
N	kittEN	
AA	cAt	*
EY	KAte	
AH	cAlm	
AE	cAre	
EH	bEt	
eh	Executive	
EE	bEEt	*
ee	candY	
IH	bIt	
ih	abilIty	
AY	bIte	
OY	bOY	
AW	tOp	
OH	tOne	*
oh	annOtate	
OW	tOWn	
AWH	tAlk	
UH	tUck	*
uh	Announce	
OOH	tOO	*
OO	tOOk	
UR	hER	
ur	buttER	

What is claimed is:

1. A computer-implemented method for enrolling a user in a continuous-speech recognition system, comprising:

analyzing acoustic content of a user utterance including multiple words;

determining, based on the analysis, whether the multiple words of the user utterance substantially match a multiple-word portion of an enrollment text; and

if the multiple words of the user utterance substantially match a multiple-word portion of the enrollment text, using the acoustic content of the user utterance to update acoustic models corresponding to the multiple-word portion of the enrollment text.

2. The method of claim **1**, wherein determining whether the multiple words of the user utterance substantially match a multiple-word portion of the enrollment text comprises using an enrollment grammar corresponding to the enrollment text.

3. The method of claim **2**, wherein determining whether the multiple words of the user utterance substantially match a multiple-word portion of the enrollment text further comprises using a rejection grammar.

4. The method of claim **3**, wherein the rejection grammar is a phoneme grammar.

5. The method of claim **4**, wherein the rejection grammar models an utterance using a set of phonemes that is smaller than a set of phonemes used by the enrollment grammar.

6. The method of claim **1**, further comprising determining an enrollment position within the enrollment text, wherein determining whether the multiple words of the user utterance substantially match a multiple-word portion of the enrollment text comprises determining whether the multiple words of the user utterance match a multiple-word portion of the enrollment text beginning at the enrollment position.

7. The method of claim **6**, further comprising displaying the enrollment text and the enrollment position.

8. The method of claim **6**, further comprising advancing the enrollment position in the enrollment text past the multiple-word portion of the enrollment text.

9. The method of claim **1**, further comprising:

determining an enrollment position within the enrollment text;

determining, using an enrollment grammar, a portion of the enrollment text beginning at the enrollment position that best matches the user utterance;

determining, using the enrollment grammar, an enrollment score for the best matching portion of the enrollment text;

determining, using a rejection grammar, a recognition candidate that best matches the user utterance; and

determining, using a rejection grammar, a rejection score for the best matching recognition candidate,

wherein determining whether the user utterance matches a portion of the enrollment text is based on the enrollment score and the rejection score.

10. The method of claim **1**, further comprising selecting the enrollment text from a plurality of enrollment texts.

11. The method of claim **10**, wherein each of the plurality of enrollment texts has a corresponding enrollment grammar, and determining whether the user utterance matches a portion of an enrollment text further comprises using the enrollment grammar corresponding to the selected enrollment text.

12. The method of claim **1**, further comprising receiving an enrollment text for use as the enrollment text.

13. The method of claim **12**, further comprising generating an enrollment grammar corresponding to the received enrollment text, wherein determining whether the multiple words of the user utterance substantially match a multiple-word portion of the enrollment text uses the generated enrollment grammar.

14. The method of claim **1**, further comprising ignoring the user utterance if the multiple words of the user utterance do not substantially match a multiple-word portion of the enrollment text.

15. A computer-implemented method for enrolling a user into a continuous-speech recognition system, comprising:

displaying an enrollment text;

displaying an enrollment position within the enrollment text;

receiving a user utterance including multiple words;

determining whether a match exists between the multiple words of the user utterance and a multiple-word portion of the enrollment text beginning at the enrollment position;

updating the enrollment position if a match exists; and

displaying the updated enrollment position.

16. The method of claim **15**, wherein displaying the enrollment position and the updated enrollment position further comprises displaying a marker at the enrollment position.

17. The method of claim **15**, wherein displaying the enrollment position and the updated enrollment position further comprises highlighting the enrollment text at the enrollment position.

18. The method of claim **15**, wherein displaying the enrollment position and the updated enrollment position further comprises displaying a cursor in the enrollment text at the enrollment position.

19. Computer software, residing on a computer-readable storage medium, comprising instructions for causing a computer to:

analyze acoustic content of a user utterance including multiple words;

determine, based on the analysis, whether the multiple words of the user utterance substantially match a multiple-word portion of an enrollment text; and

use the acoustic content of the user utterance to update acoustic models corresponding to the multiple-word portion of the enrollment text if the multiple words of the user utterance substantially match a multiple-word portion of the enrollment text.

20. A speech recognition system for enrolling a user, comprising:

a display for displaying an enrollment text to a user;

an input device for receiving speech signals;

a processor for:

determining a user utterance including multiple words from a received speech signal;

analyzing acoustic content of the user utterance;

determining, based on the acoustic analysis, whether the multiple words of the user utterance substantially match a multiple-word portion of an enrollment text; and

using the user utterance to update acoustic models corresponding to the multiple-word portion of the enrollment text if multiple words of the user utterance substantially match a multiple-words portion of the enrollment text.

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